New era in TeV dark matter gamma-ray search

(what we learned from the Fermi LAT and prospects for the CTA)

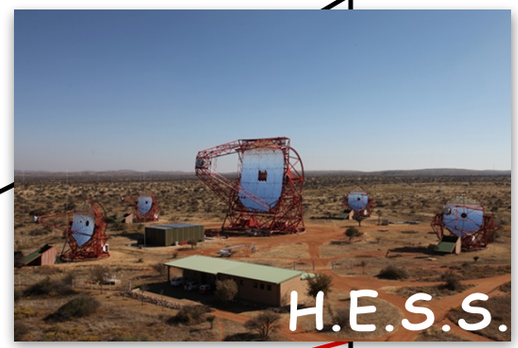
Gabrijela Zaharijas

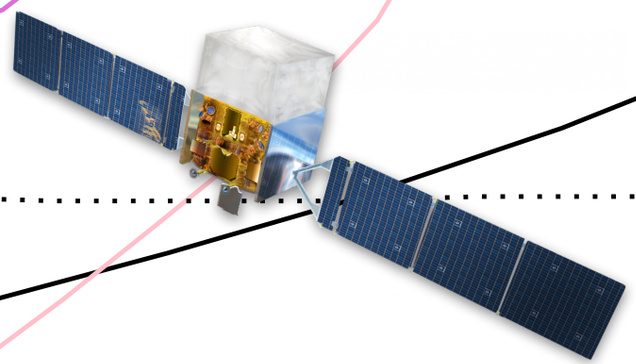
for the CTA consortium

Un. of Nova Gorica and INFN, Trieste

work within the **CTA DM working group** (with **T. Bringmann, C. Eckner, A. Sokolenko, L. Yang**)

The status of DM search





EFT assumed

Thermal WIMP

Thermal Relic Cross Section
(Steigman+ 2012)

LAT dSphs: Ackermann+ (2015)
HESS, MW Halo: Lefranc+ (2015)
Direct: LUX (2012), XENON100 (2012), COUPP (2012)
LHC: ATLAS (2013), CMS (2012)

$b\bar{b}$

$\langle \sigma v \rangle$ [cm^3 s^{-1}]

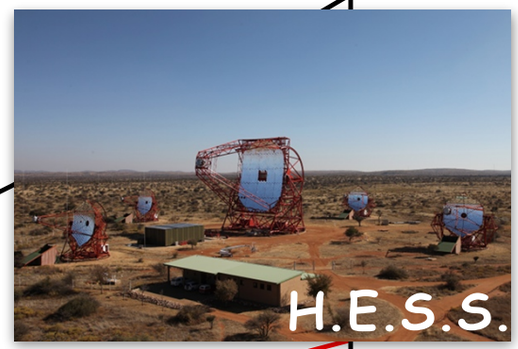
10^{-23} 10^{-24} 10^{-25} 10^{-26} 10^{-28}

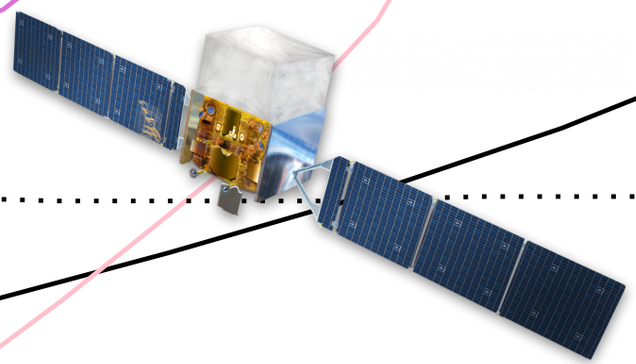
10^1 10^2 10^3 10^4

m_χ [GeV]

[Charles+, Phys.Rept.(2016)]

The status of DM search





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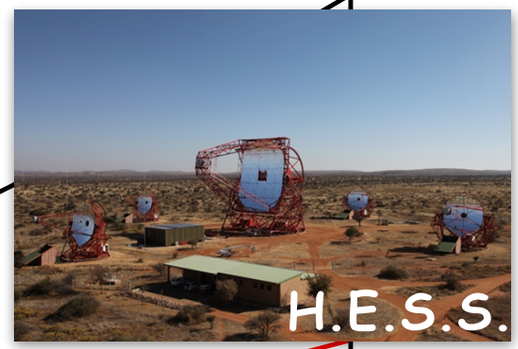
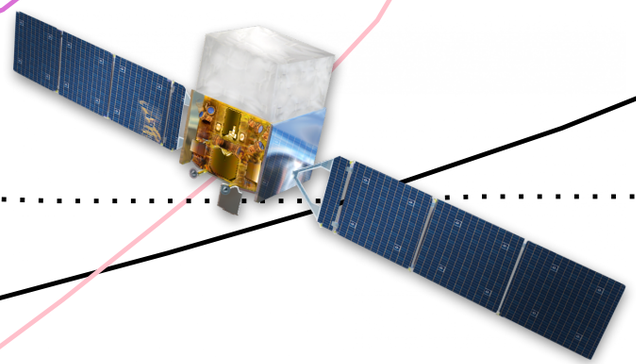
m_χ [GeV

- **Good complementarity between direct, collider and indirect search**

The status of DM search





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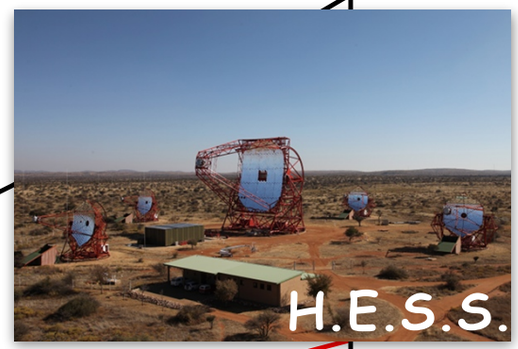
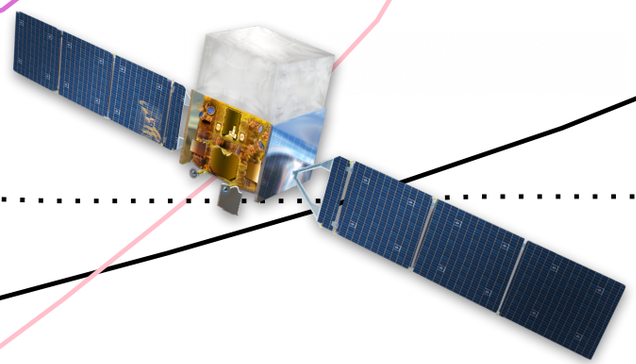
- **Good complementarity between direct, collider and indirect search**
- **WIMPs, 'not even slightly' ruled out (Leane+, PRD (2018))**

The status of DM search





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10^2

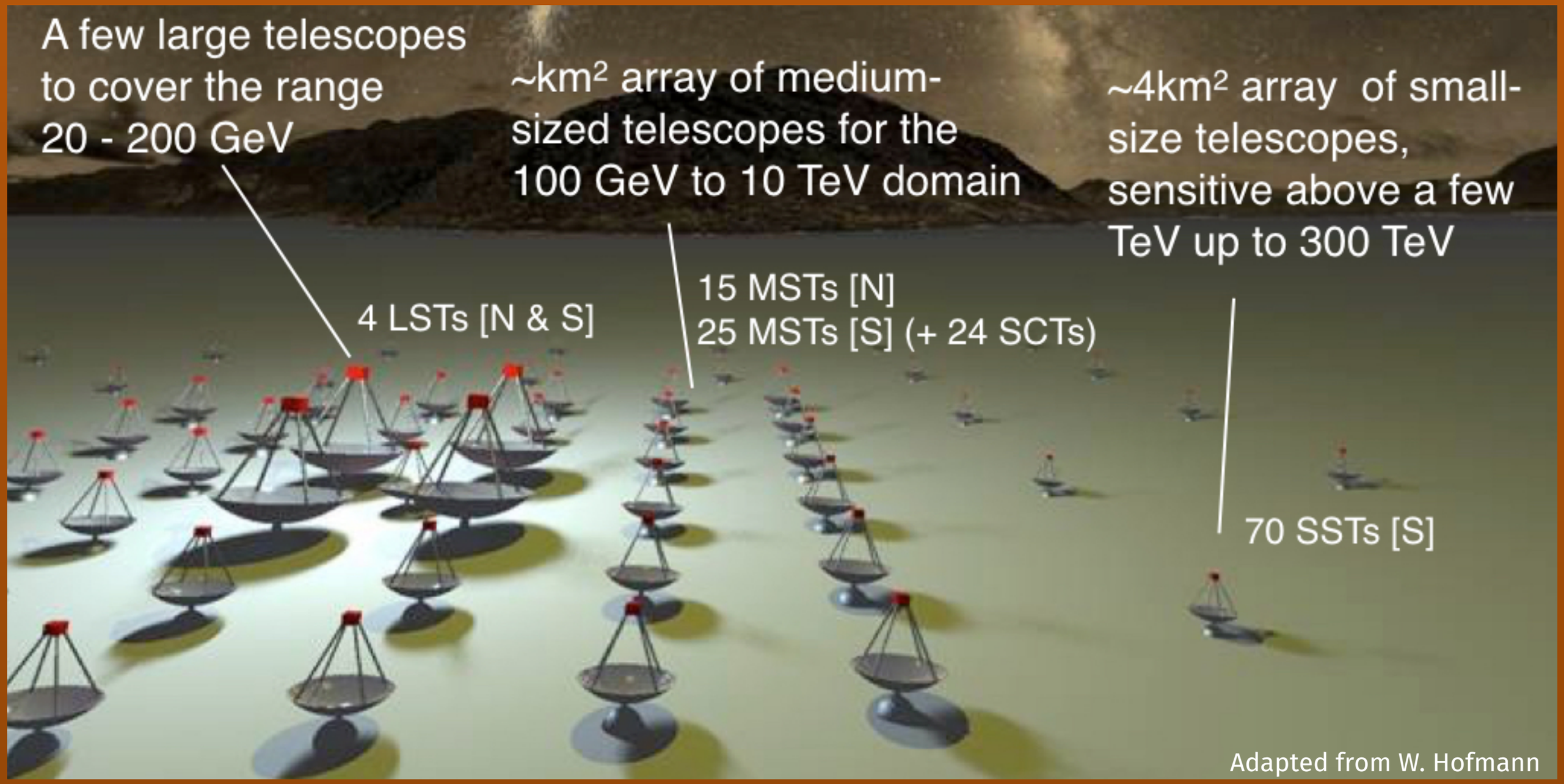
m_χ [GeV

- Good complementarity between direct, collider and indirect search
- WIMPs, 'not even slightly' ruled out (Leane+, PRD (2018))
- TeV mass domain not yet explored

Cherenkov Telescope Array (CTA)

- one of the biggest projects in high energy astrophysics

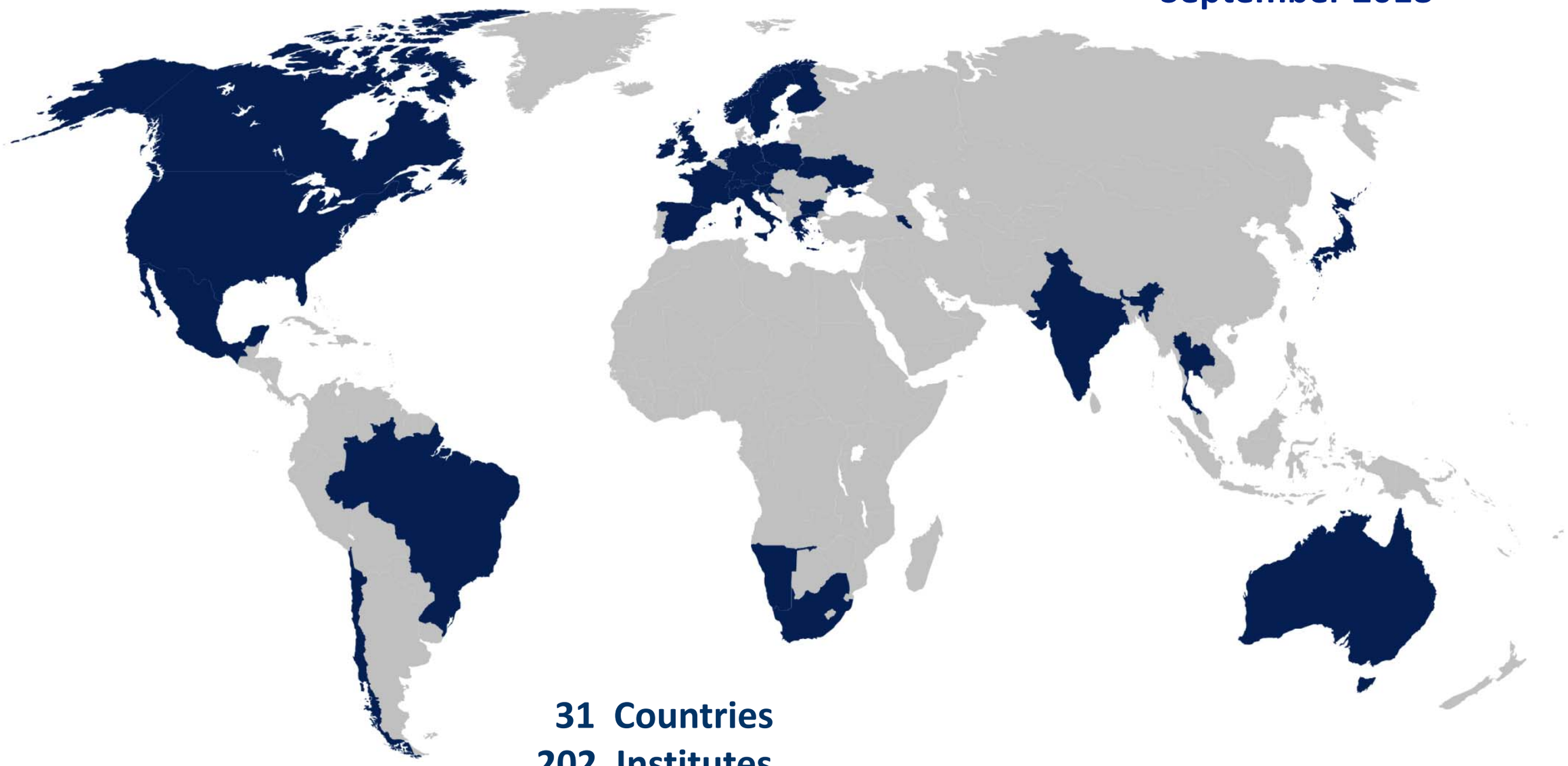
Holds promise of exploring the thermal WIMP TeV+ region.



Adapted from W. Hofmann

Consortium Membership

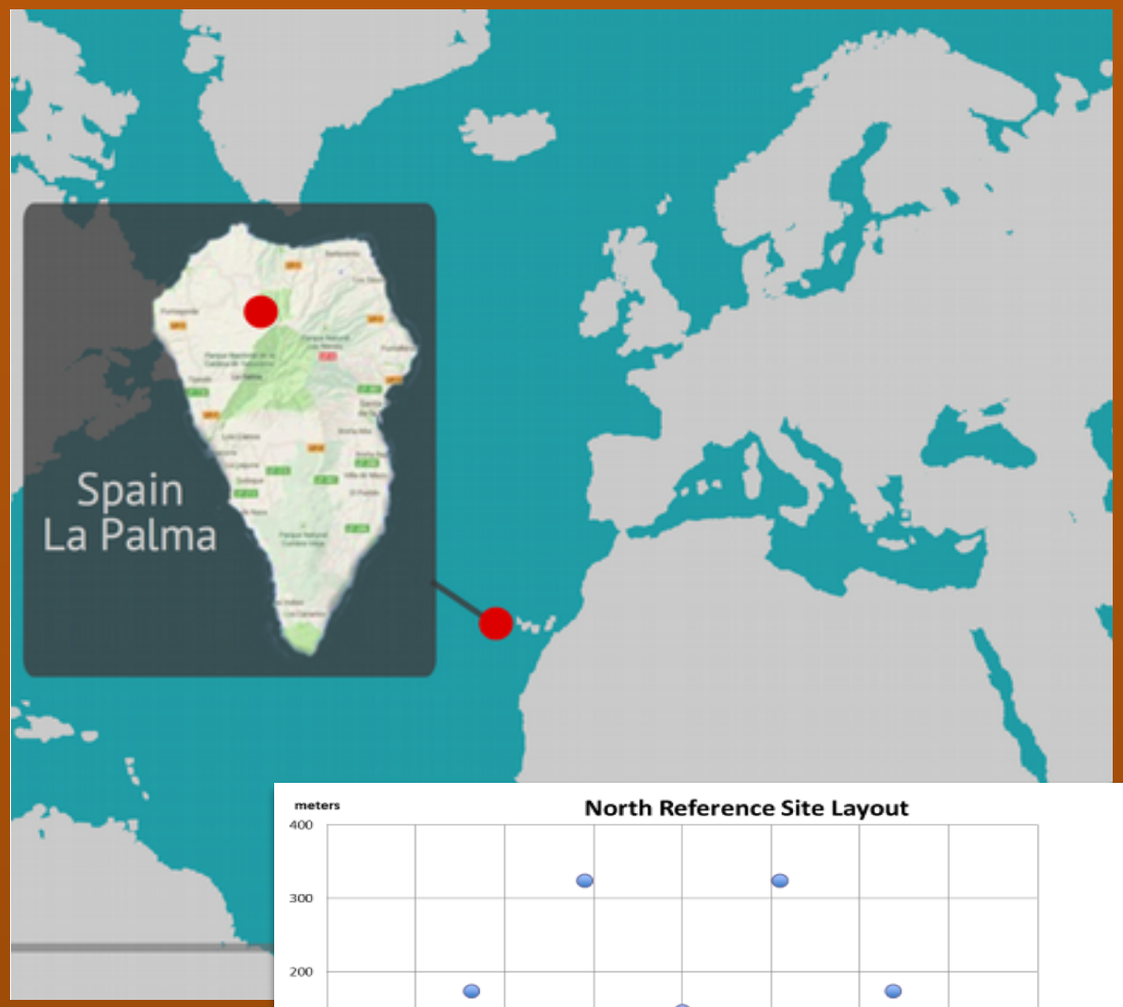
September 2018

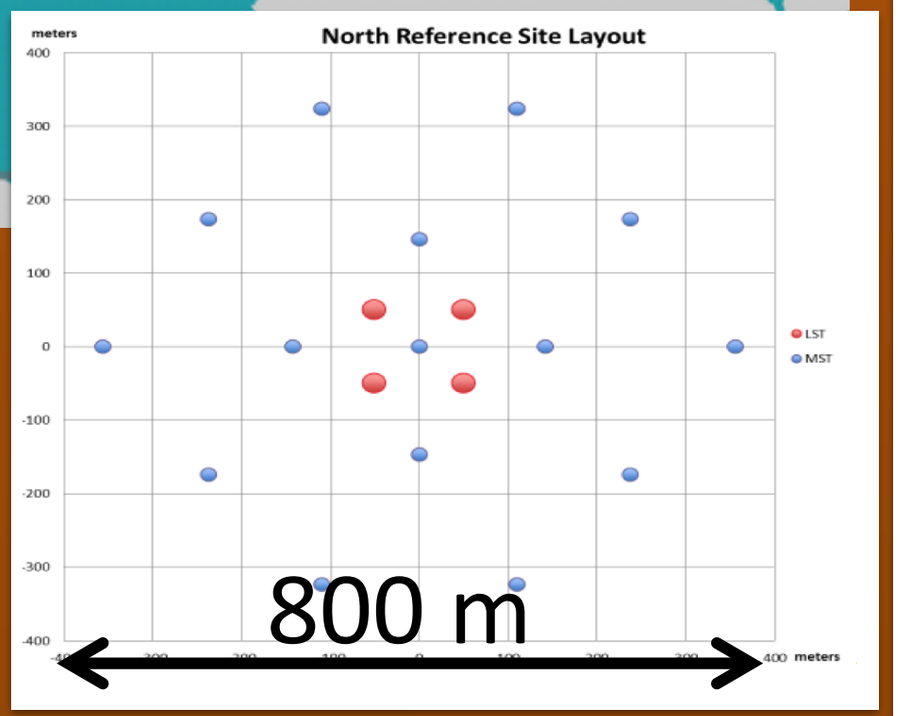


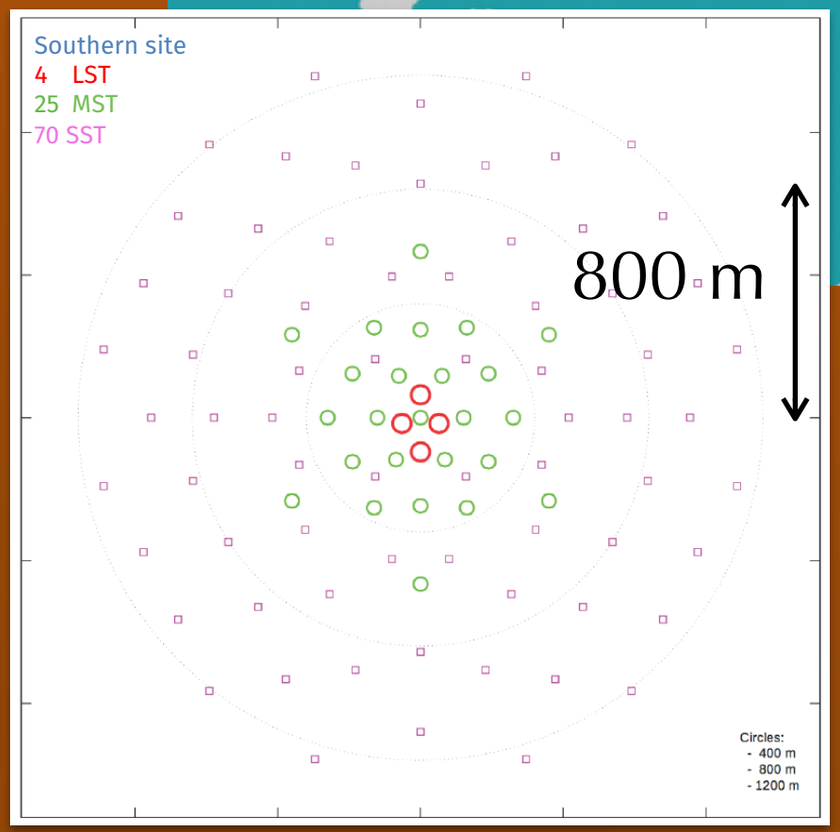
31 Countries
202 Institutes
1451 Members (508 FTE)

CTA

sites and example telescope layouts



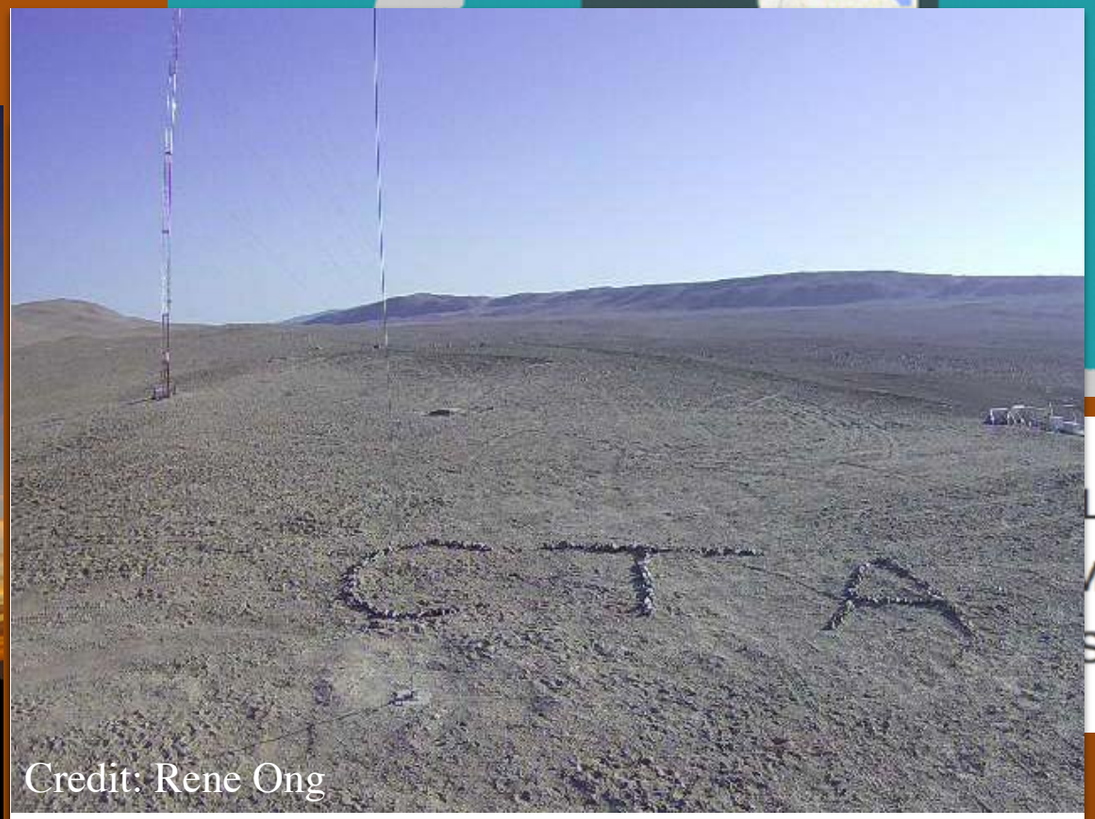




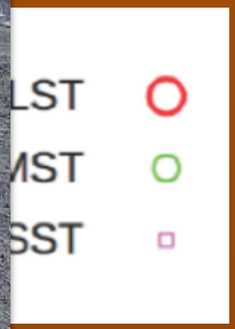
[credit: T. Hassan, CTA consortium]

CTA

sites and example telescope layouts



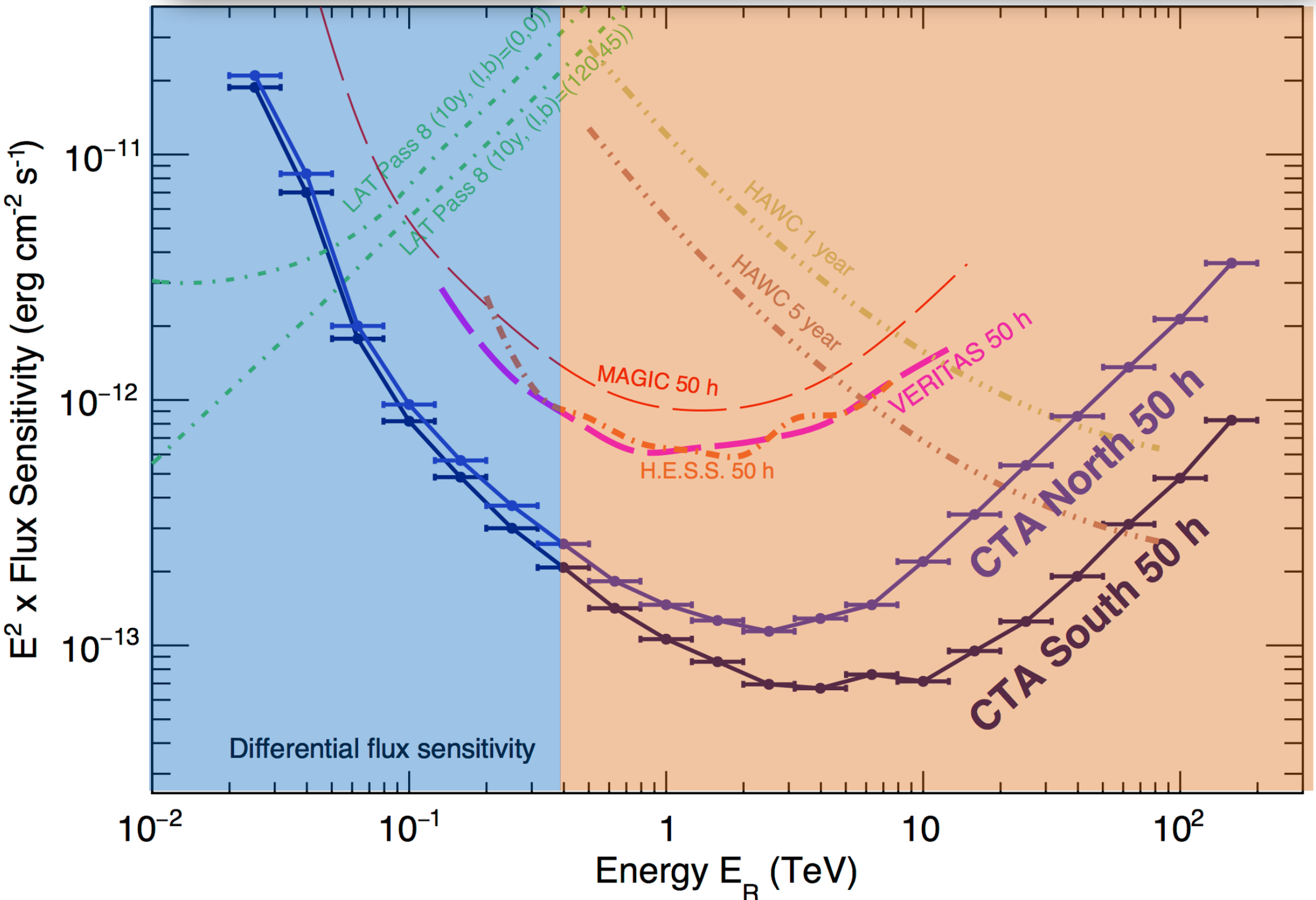
CTA-S location (Paranal)



Hassan,
ortium]

CTA

Performance



Focusing at the Galactic Centre

Slide courtesy of L. Tibaldo

8° CTA FoV

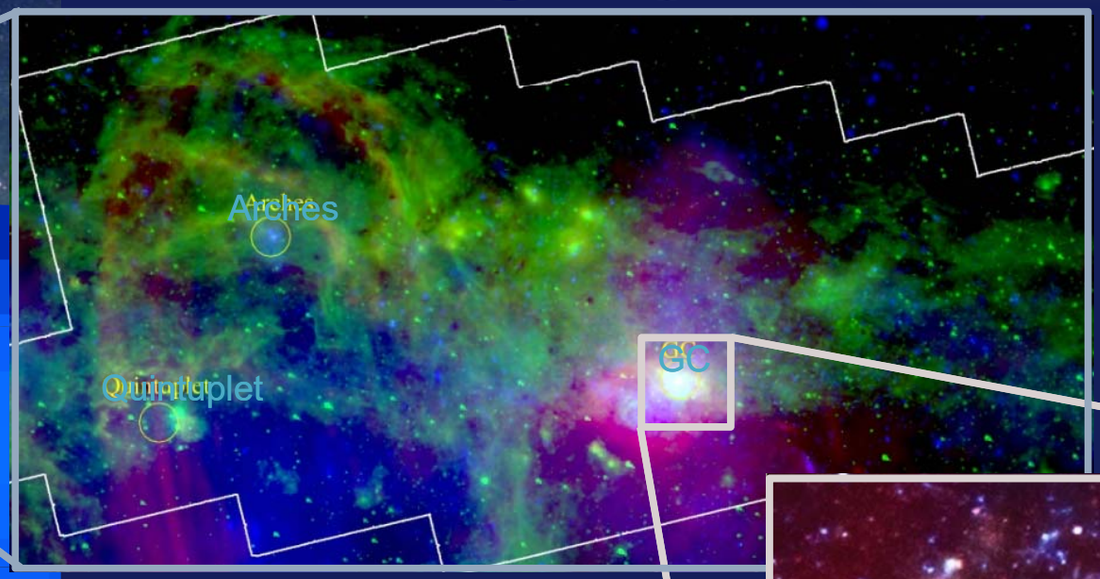
DM template

Fermi PSF (50 GeV)

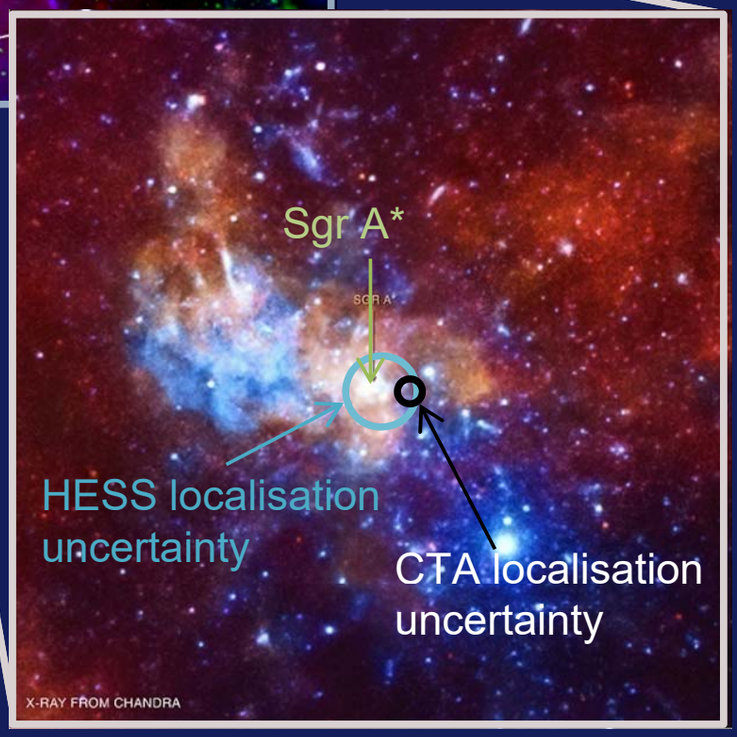
HESS PSF (3 TeV)

CTA PSF (3 TeV)

The brightest point on the dark matter gamma-ray sky



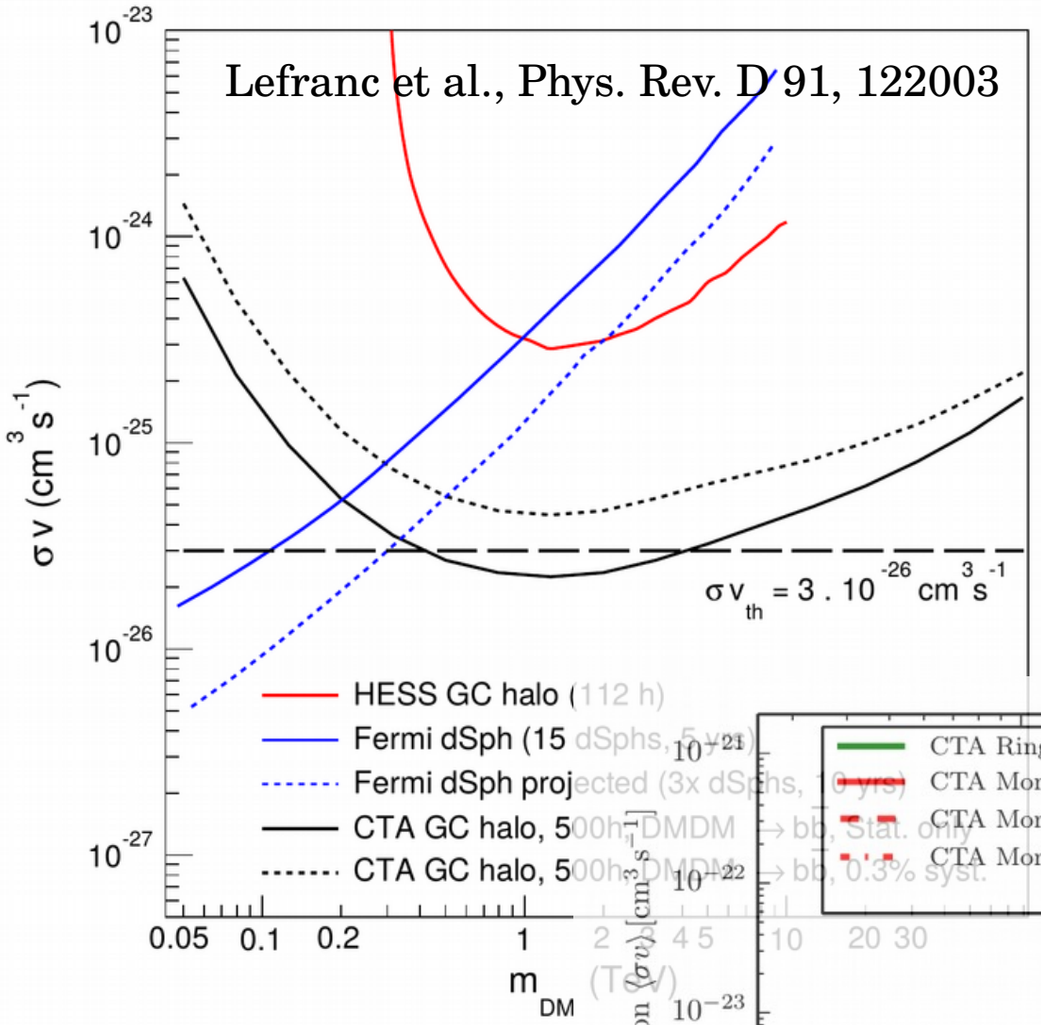
VLA + Spitzer + Chandra
Wang+ 2010 MNRAS 492 895

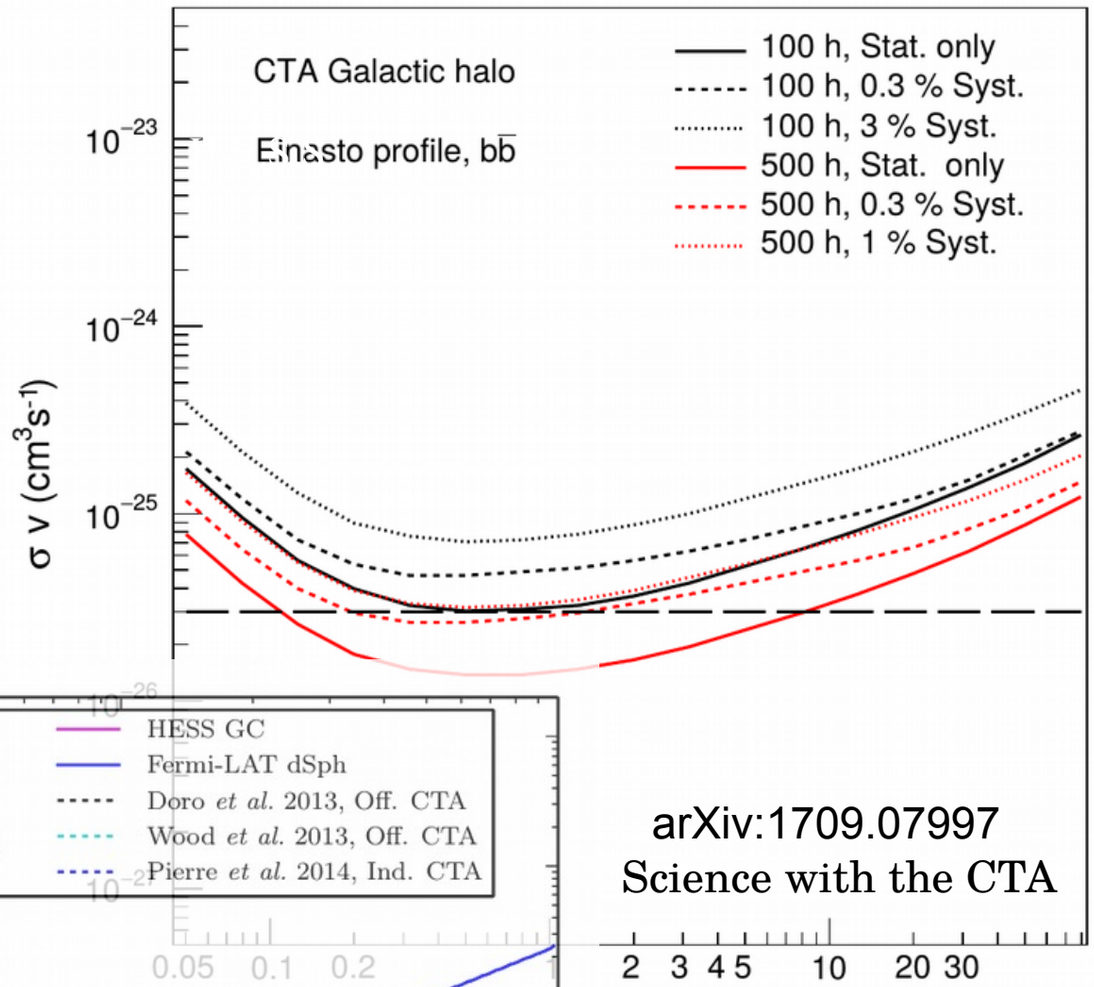


Spitzer
Credit: NASA/JPL Caltech
+ *Fermi* bubbles
Ackermann+ 2017 ApJ 840 43A

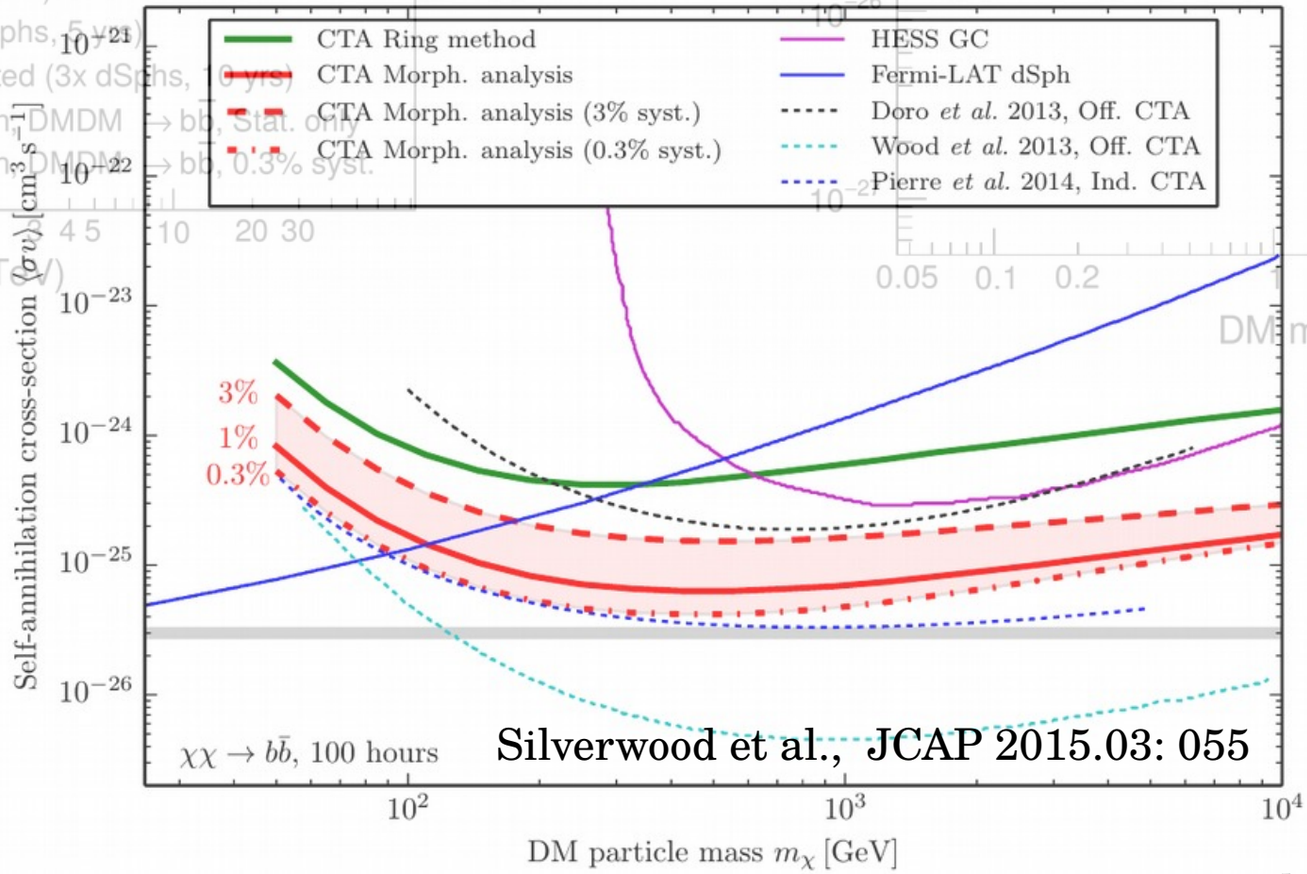
- wealth of VHE diffuse emission & sources, including the only known PeVatron
- giant particle outflow (*Fermi* bubbles)

CTA DM sensitivity @GC in previous analyses





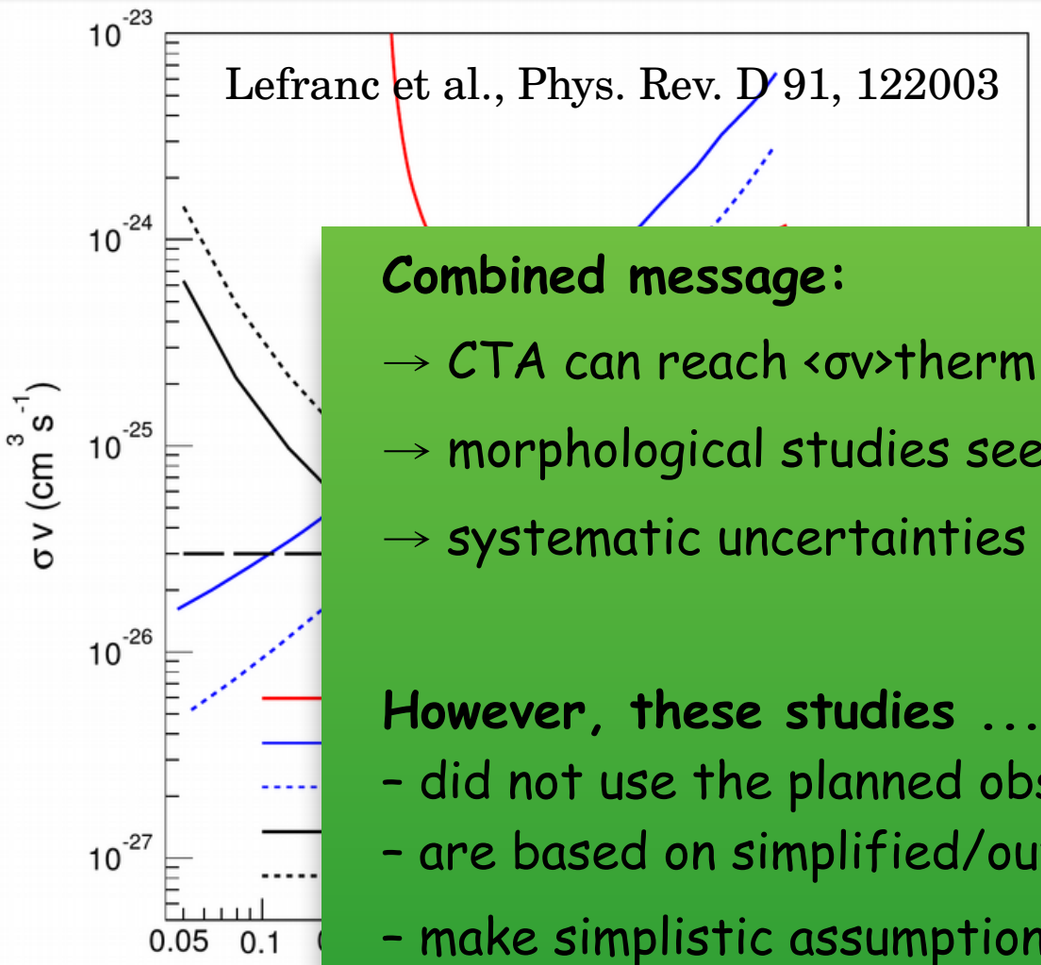
arXiv:1709.07997
Science with the CTA

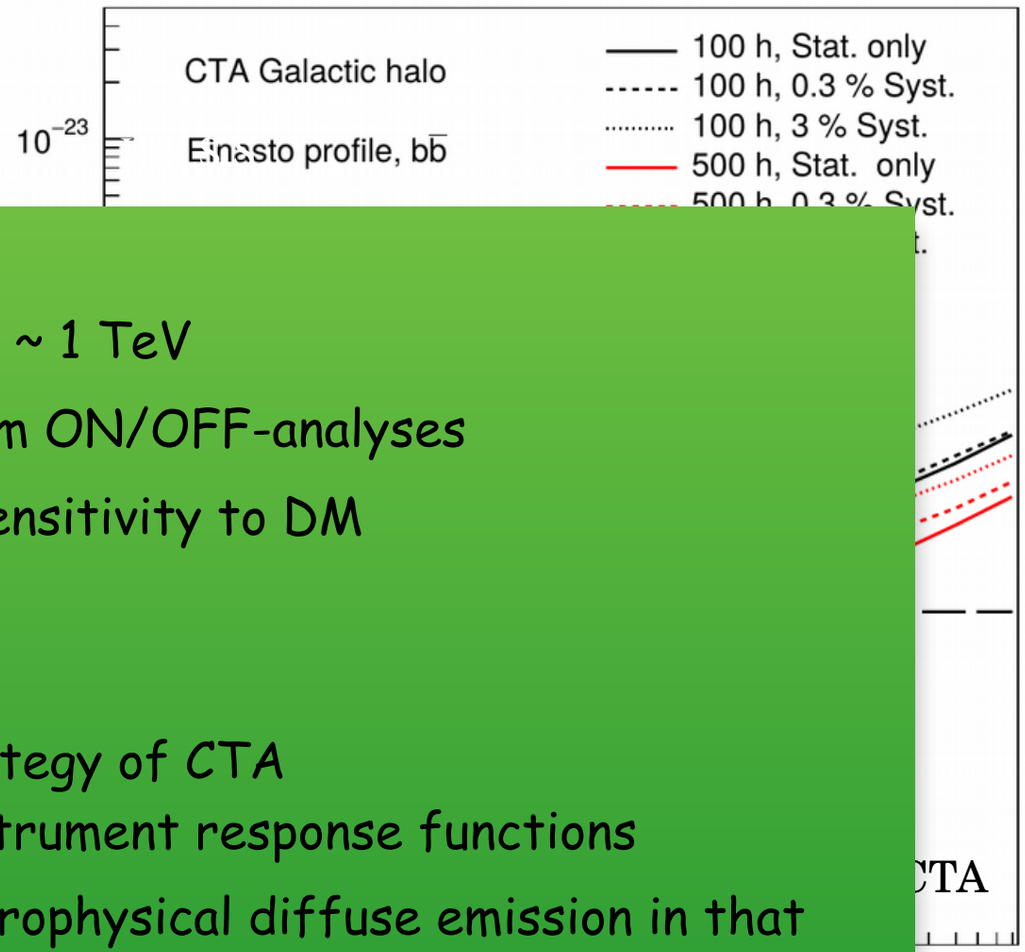


Silverwood et al., JCAP 2015.03: 055

[slide courtesy of C. Eckner]

CTA DM sensitivity @GC in previous analyses





Combined message:

→ CTA can reach <σv>therm for DM masses ~ 1 TeV

→ morphological studies seem to outperform ON/OFF-analyses

→ systematic uncertainties dominate the sensitivity to DM

However, these studies ...

- did not use the planned observational strategy of CTA
- are based on simplified/outdated CTA instrument response functions
- make simplistic assumptions about the astrophysical diffuse emission in that region.

What is the realistic DM sensitivity, given state-of-the-art models of Galactic diffuse emission (GDE), Instrumental Response Functions (IRFs) and CTA's observational strategy?

DM particle mass m_χ [GeV]

CTA Consortium paper on DM sensitivity at the Galactic Centre

- status report

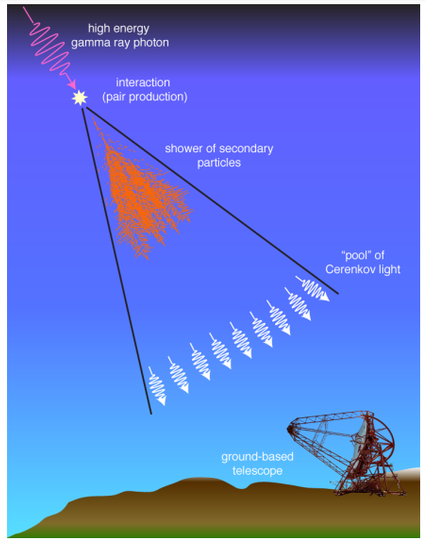
Input:

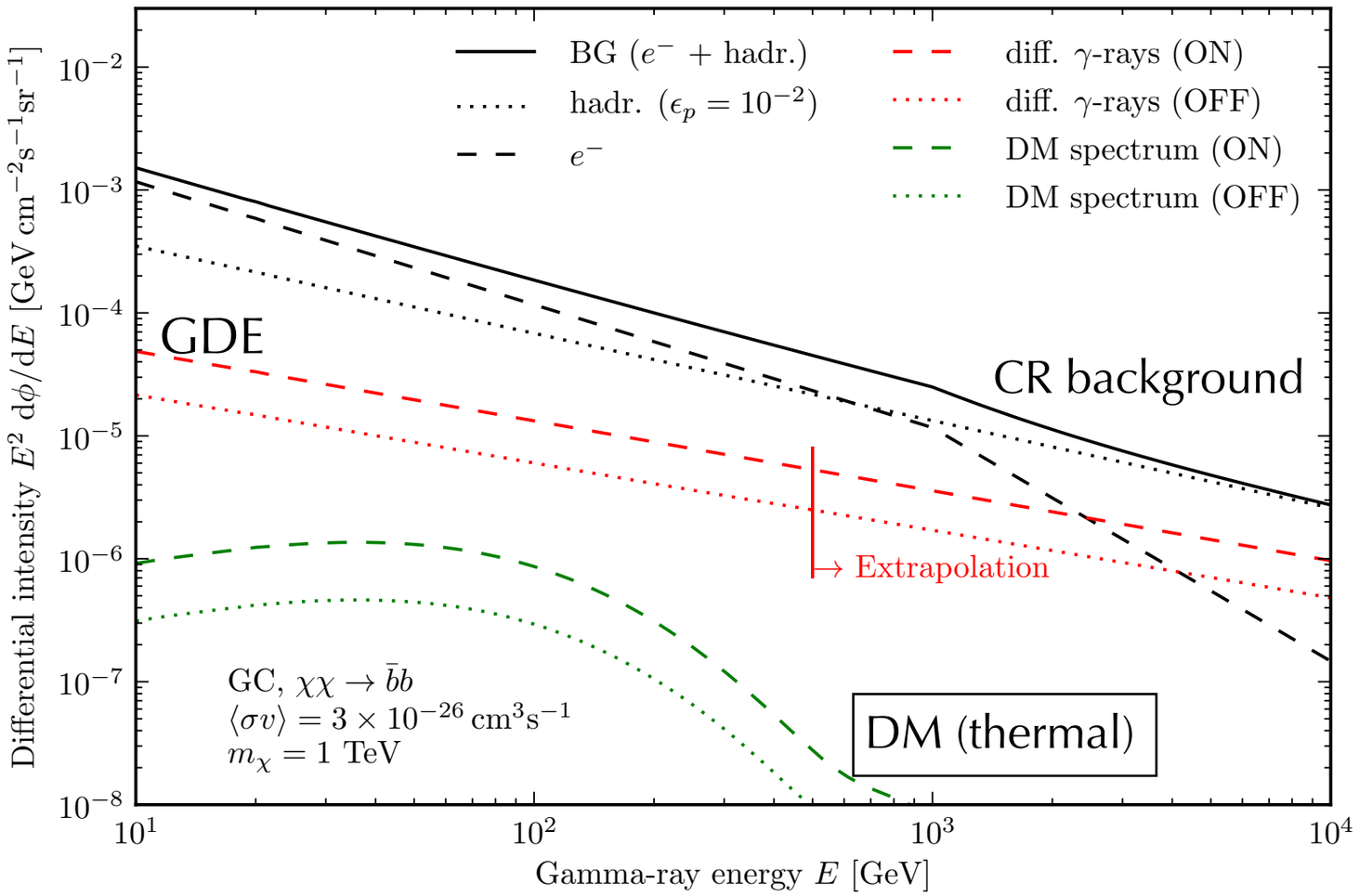
→ **CR backgrounds:** 500h *GC* **survey** observation, prod3IRFs and CTOOLs

→ GDE

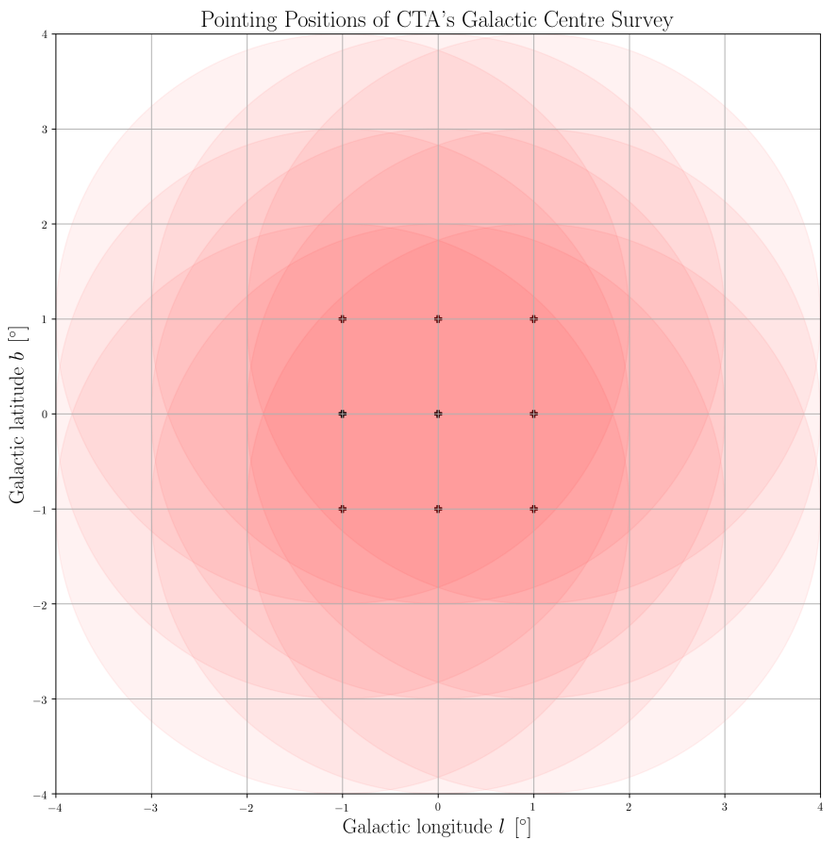
→ DM

→ point sources, Fermi bubbles…





[Silverwood+, JCAP (2015)]



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→ DM

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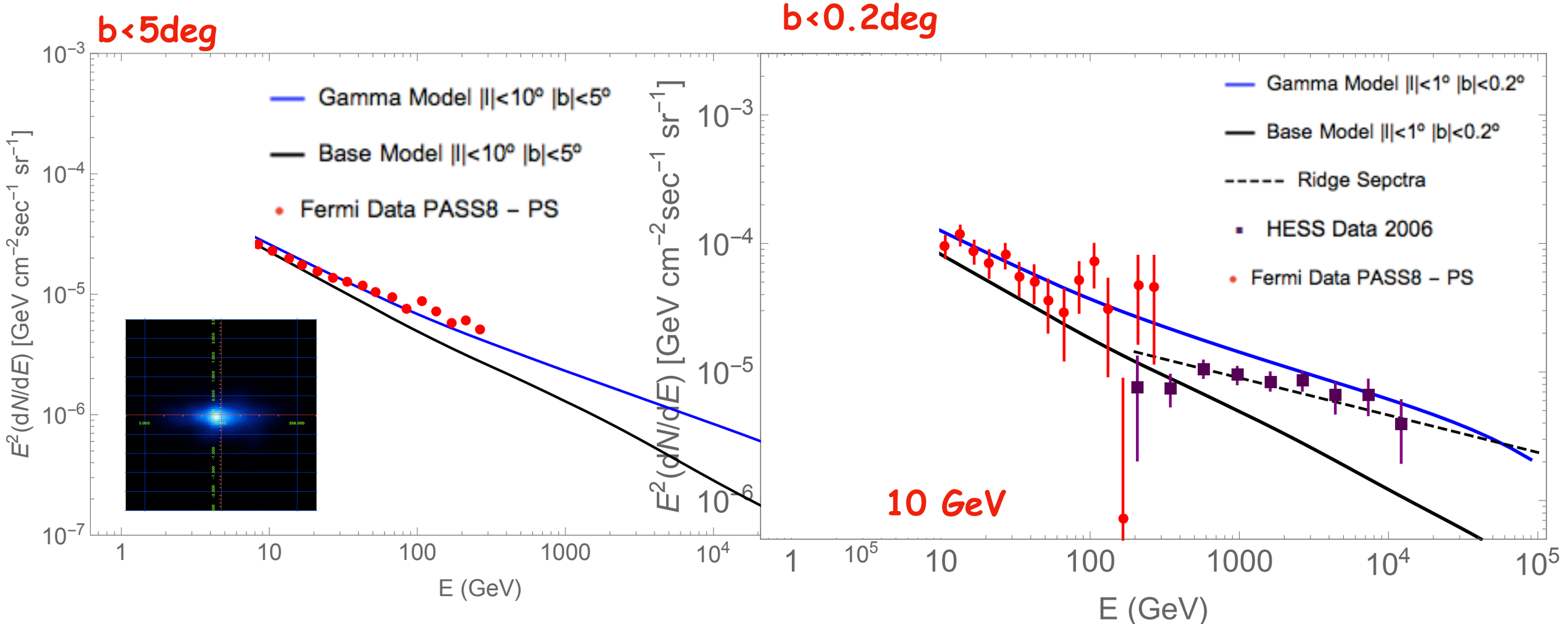

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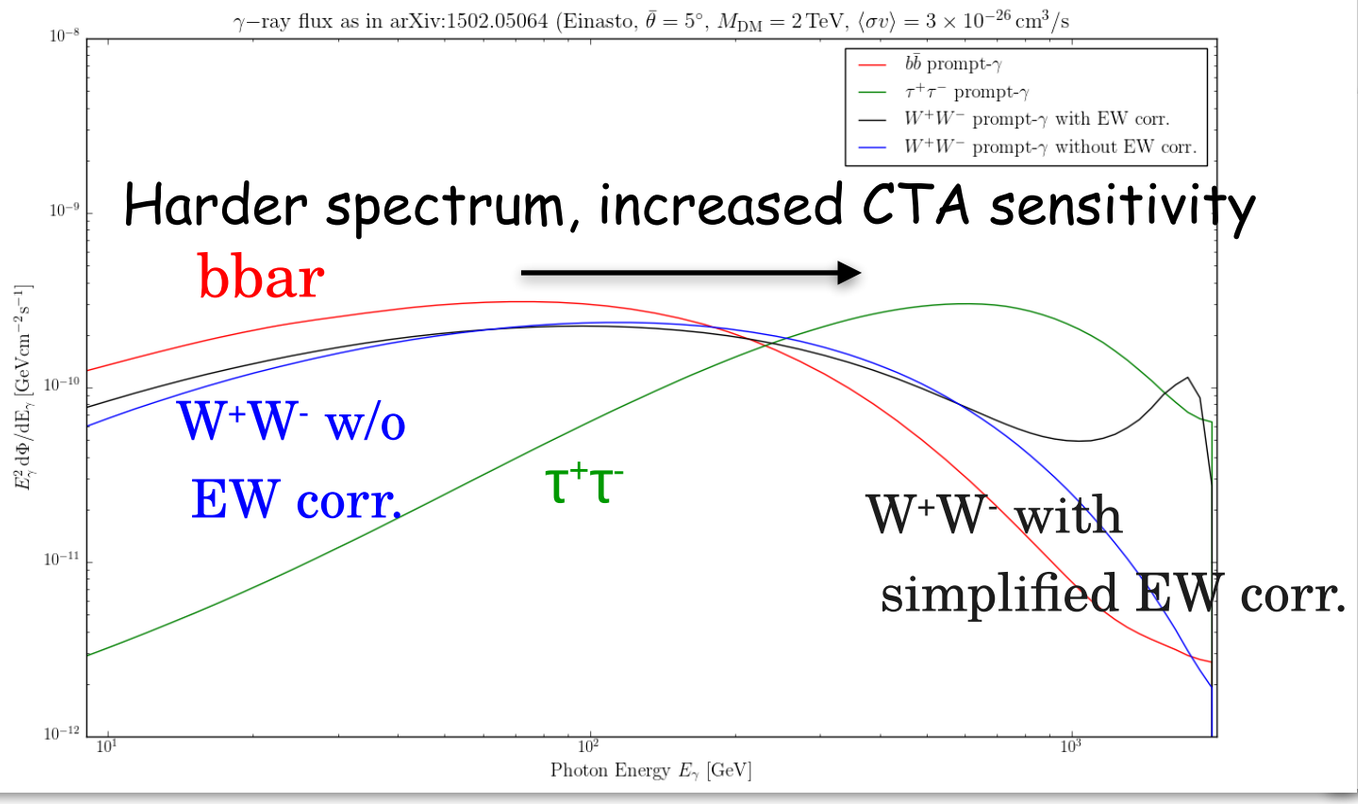
→ CR backgrounds: 500h GC **survey** observation, prod3IRFs and CTOOLs

→ GDE: based on Gaggero, D. +, PRL(2017), '**gamma-**' and '**base-**' models

→ **DM**: spectrum (**PPPC4DMID**) and morphology (**CLUMPY**)

→ point sources, Fermi bubbles… (ongoing)

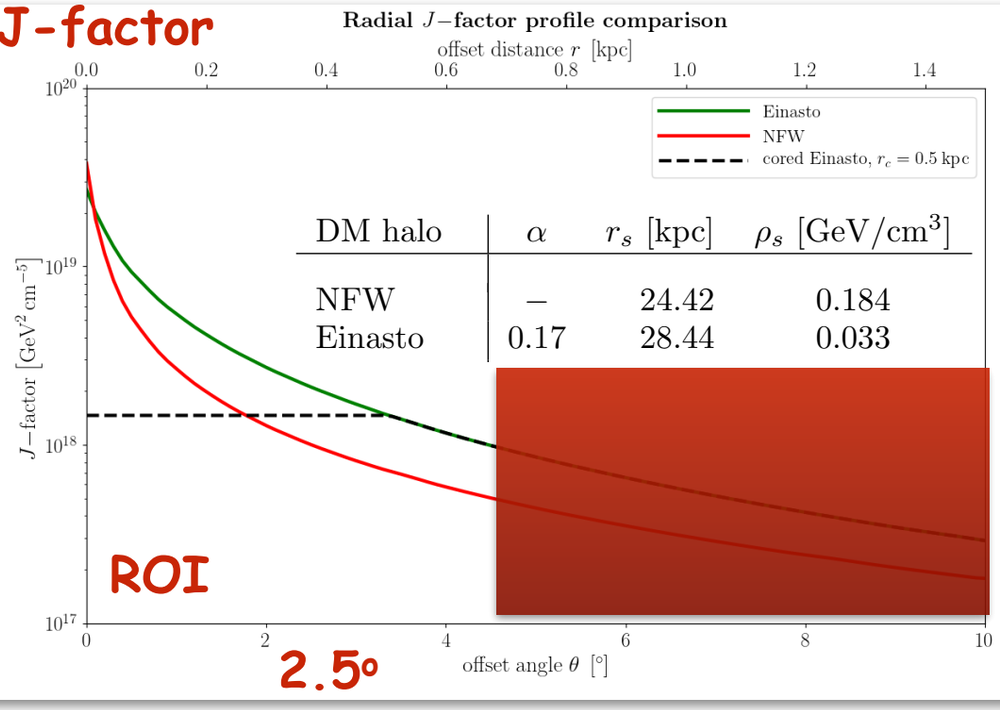
spectra taken from Cirelli et al., arXiv:1012.4515 ("PPPC")



Spatial distribution:

- **Cusp** (Einasto, NFW)
- Ein smoothed with 500 pc **core**

J-factor



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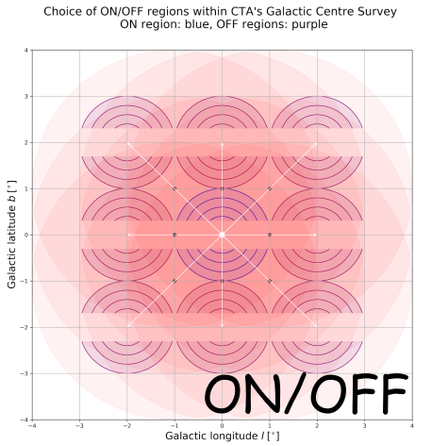
Analysis:

→ **Morphological**

→ ON/OFF: hard in presence of bright diffuse emission

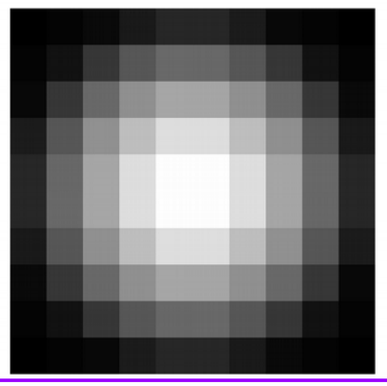


Likelihood function (including systematics → α_{ij}, β_i)

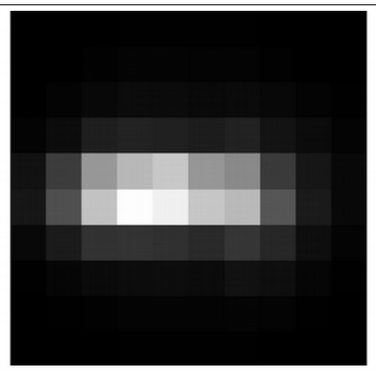
$$\mathcal{L}(\boldsymbol{\mu}, \boldsymbol{\alpha}, \boldsymbol{\beta} | \boldsymbol{n}) = \prod_i \frac{1}{\sqrt{2\pi}\sigma_\beta} e^{-\frac{(1-\beta_i)^2}{2\sigma_\beta^2}} \prod_j \frac{(\mu_{ij}\alpha_{ij}\beta_i)^{n_{ij}}}{\sqrt{2\pi}\sigma_\alpha \cdot n_{ij}!} e^{-\mu_{ij}\alpha_{ij}\beta_i} e^{-\frac{(1-\alpha_{ij})^2}{2\sigma_\alpha^2}}$$

(energy bins) (spatial bins)

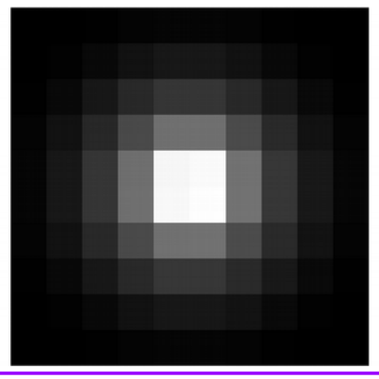
→ using mock data **n** (Asimov data set)



Residual Instrumental Background (CR)



Galactic Diffuse Emission (GDE)



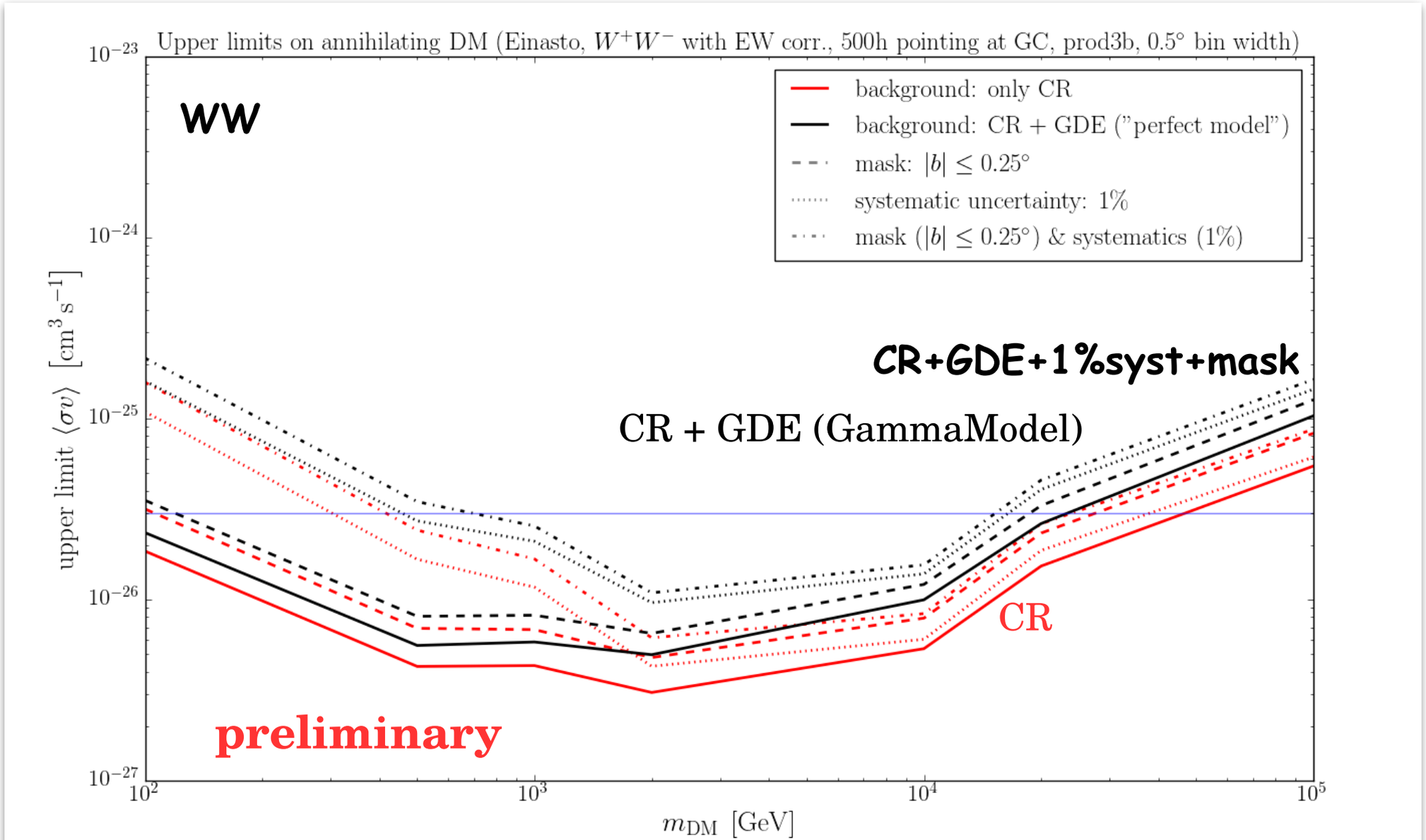
Dark Matter (DM) Signal

Syst uncertainty in the 'default' approach - each pixel&en bin can independently fluctuate by α (~1%).

CTA Consortium paper on DM sensitivity at the Galactic Centre - status report

Some results:

→ with **Morphological analysis, CR+GDE +1 % systematics**



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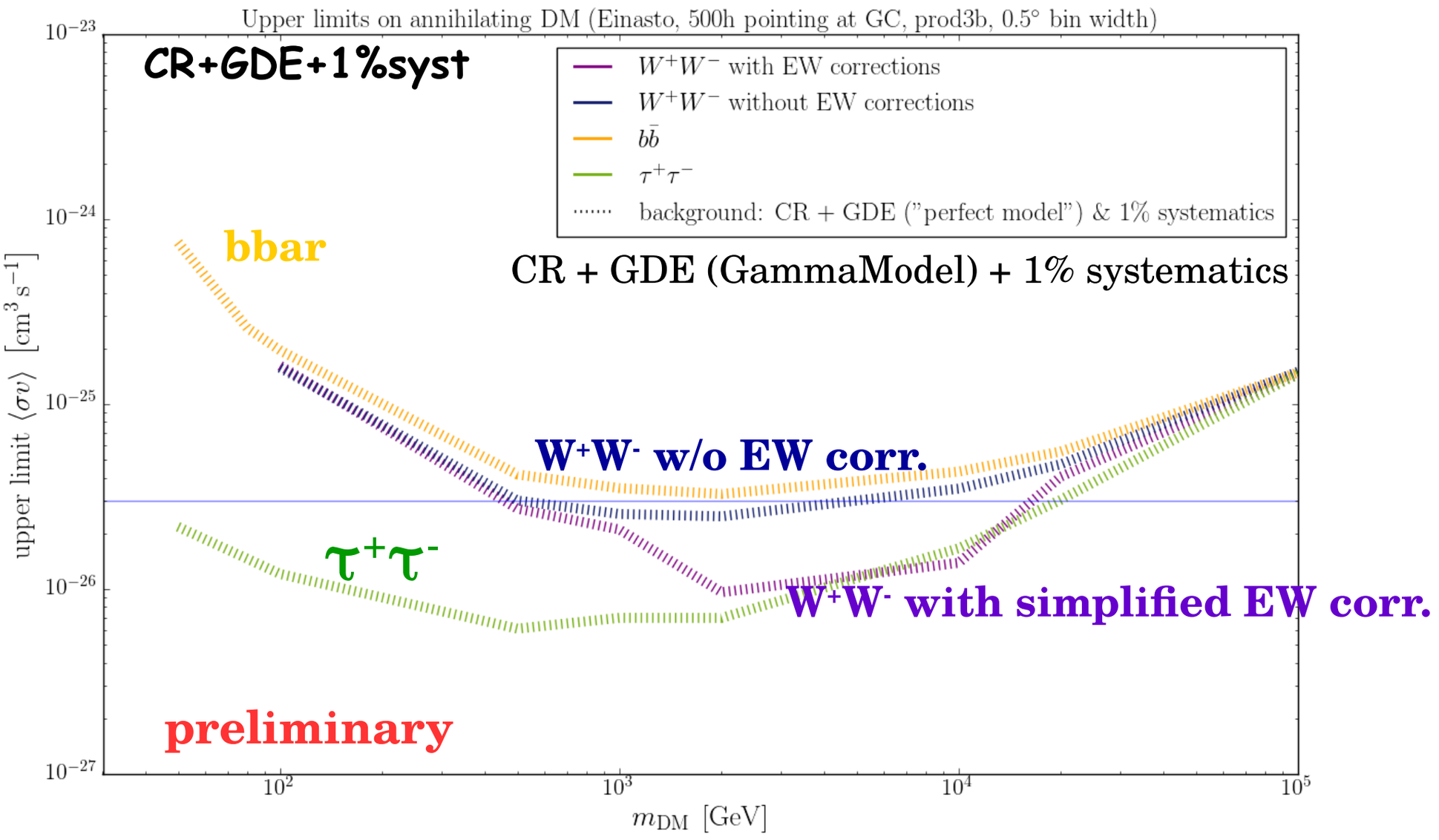

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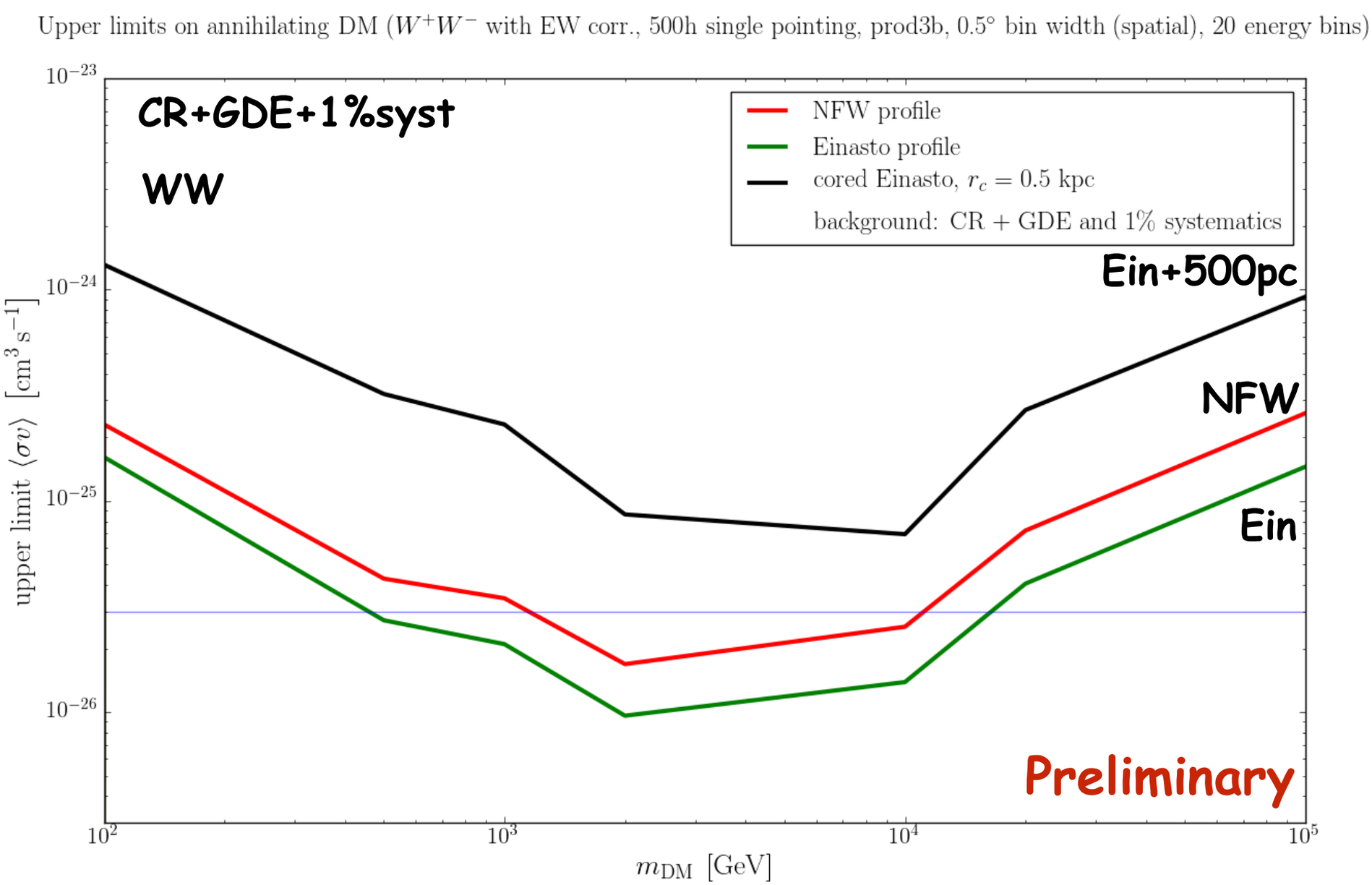
How do different DM density profiles compare?



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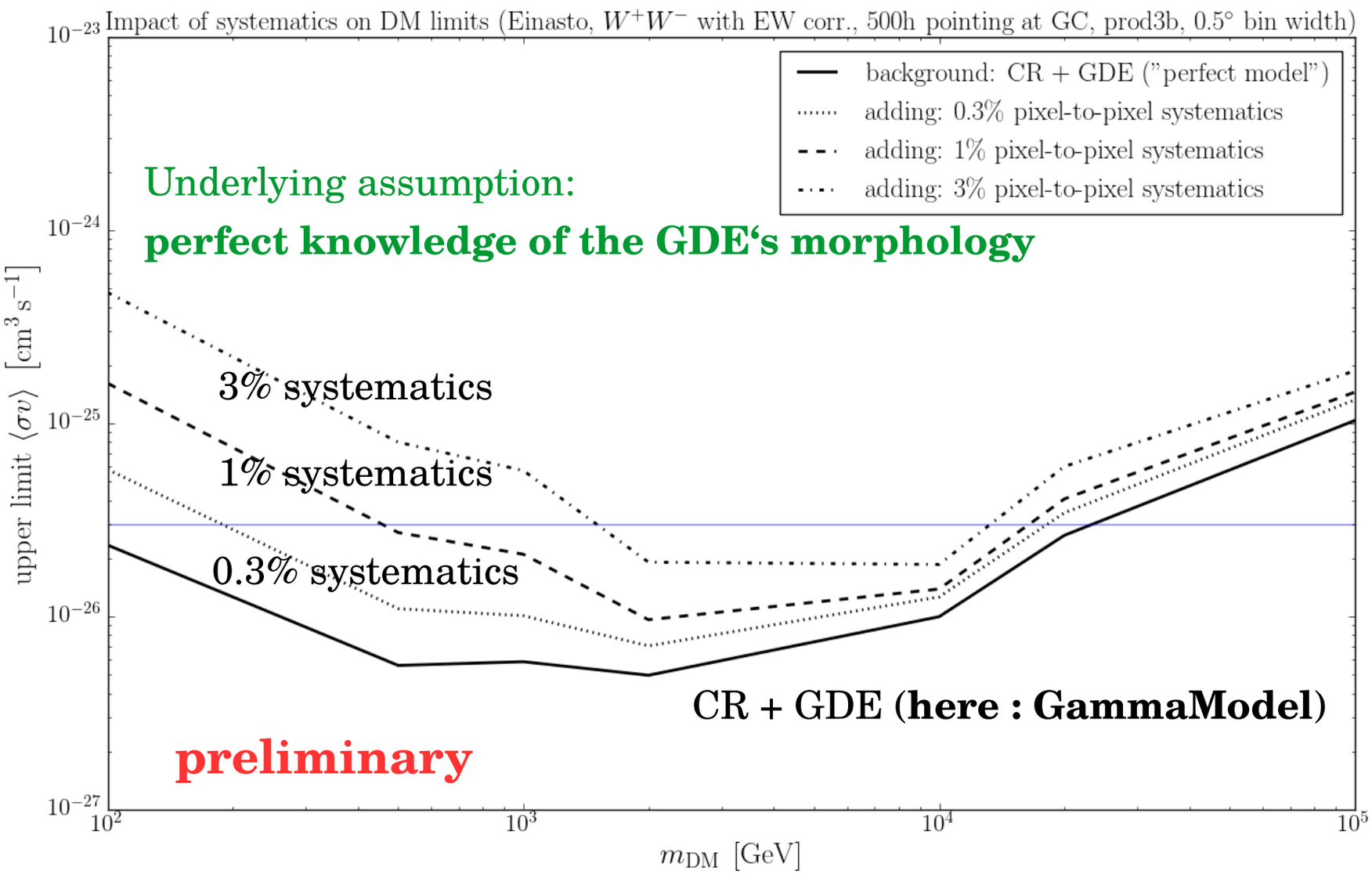
→ What is the effect of varying the level of pixel-to-pixel systematics?



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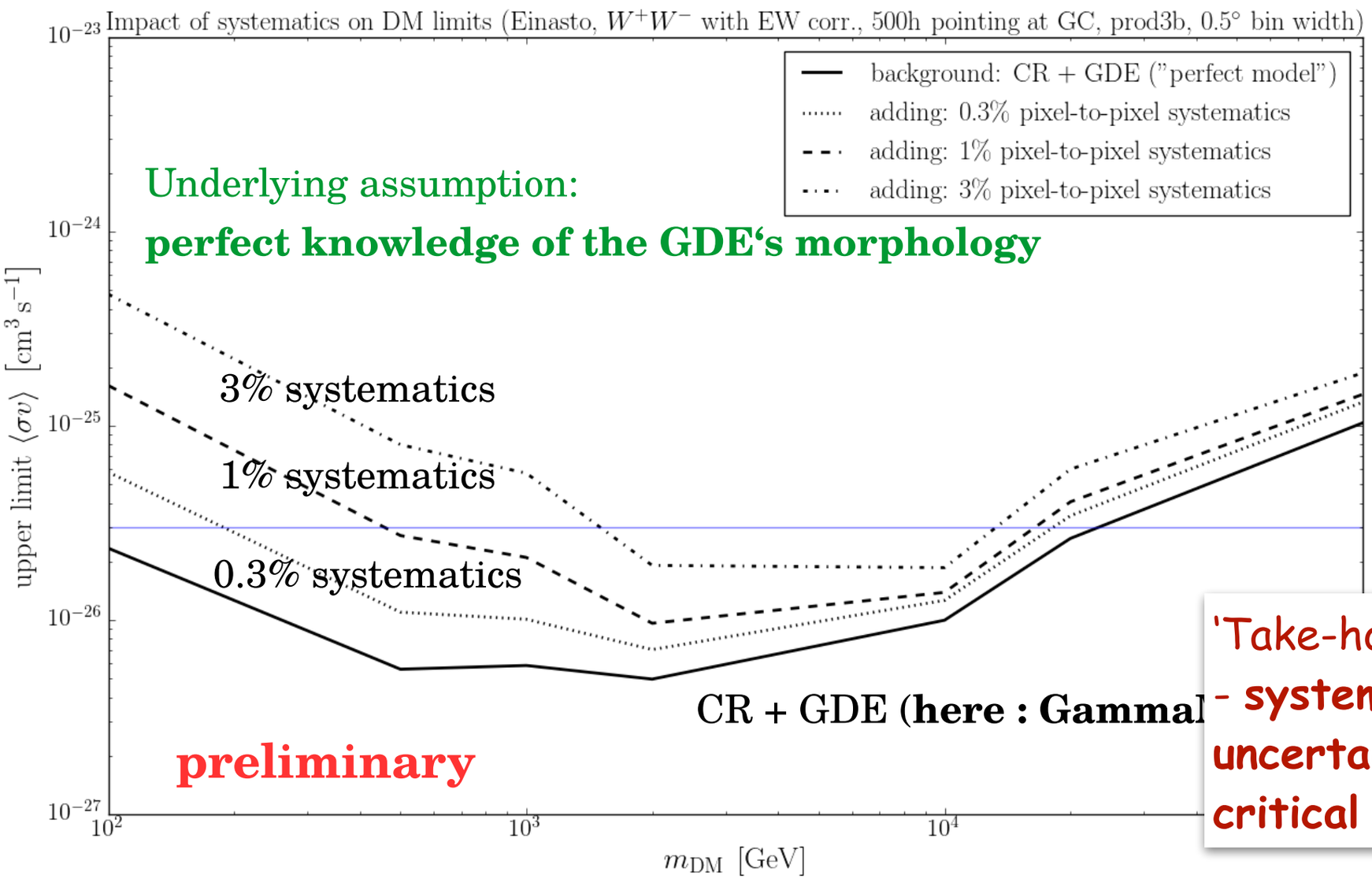

'Take-home' message:
- systematic uncertainty the most critical parameter.

CTA Consortium paper on DM sensitivity at the Galactic Centre

- status report

Some results:

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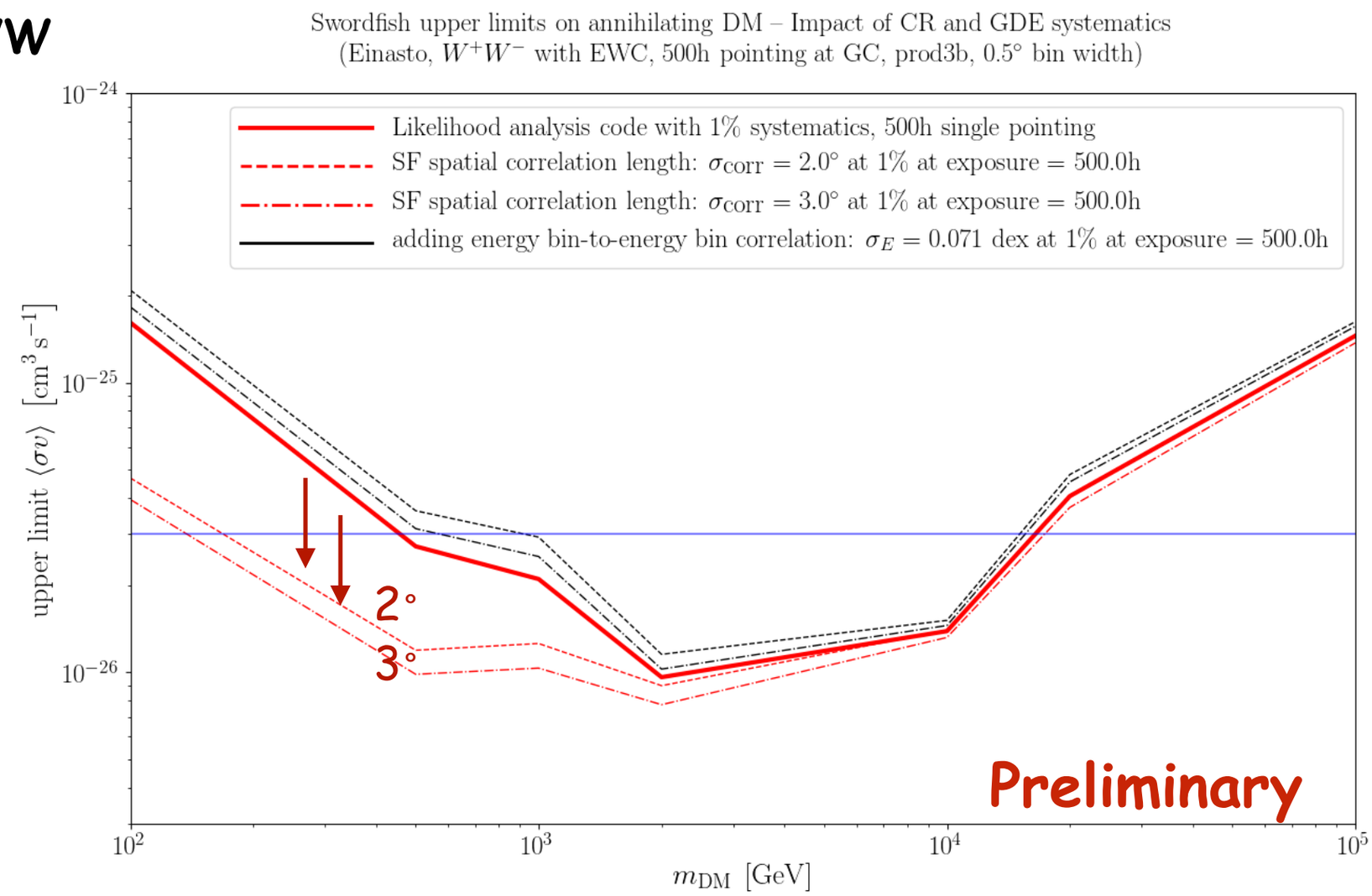
→ **Exploring systematics correlations with the Swordfish tool** (Edwards&Weniger, JCAP (2018))

WW



Syst of 1% on CR background, but **correlated with 2&3 deg correlation length**

CTA Consortium paper on DM sensitivity at the Galactic Centre - status report

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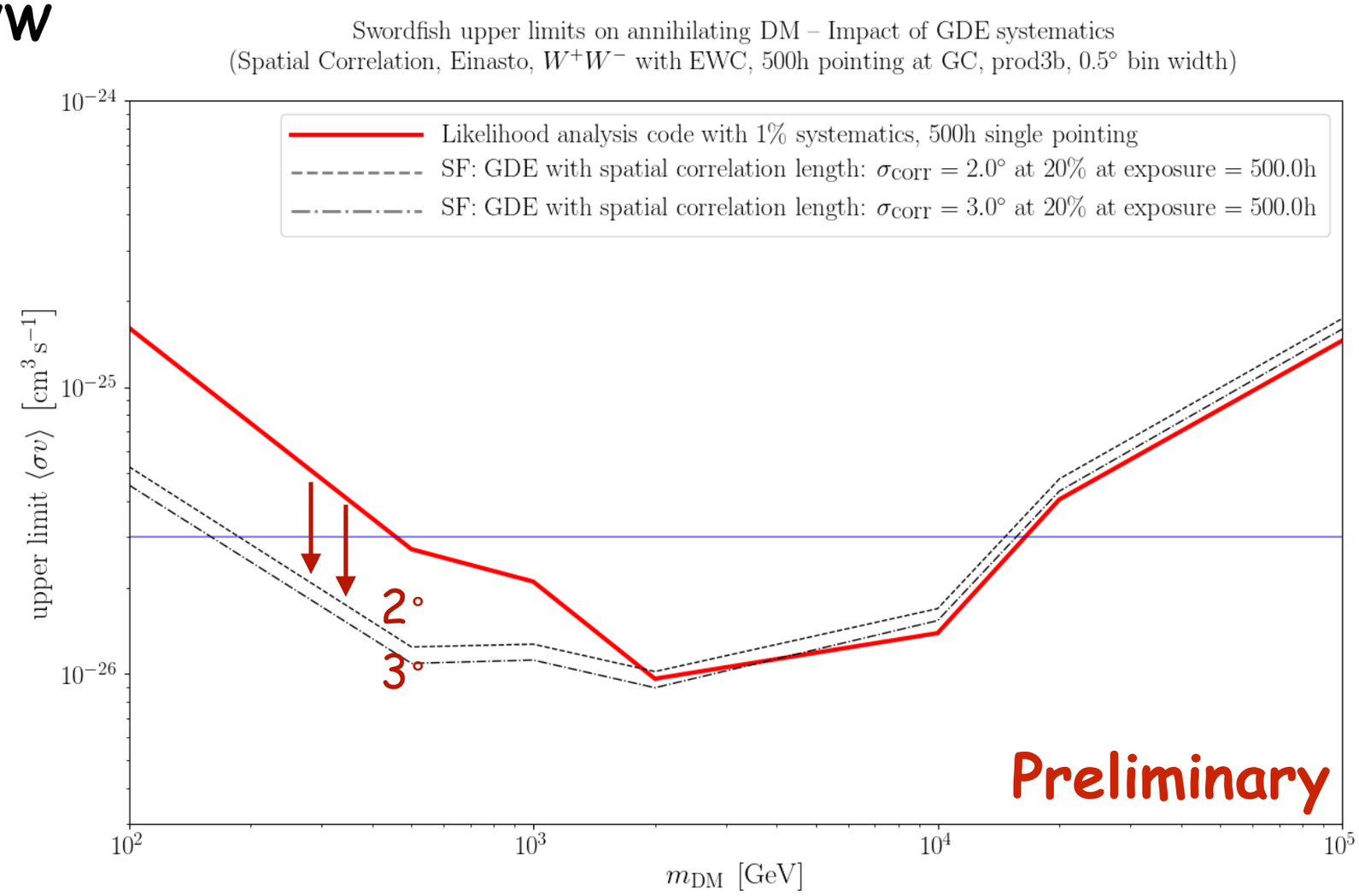

Assumes that we know CR backgrounds perfectly and have **20% syst on GDE, correlated at 2 and 3 deg length.**

CTA Consortium paper on DM sensitivity at the Galactic Centre - status report

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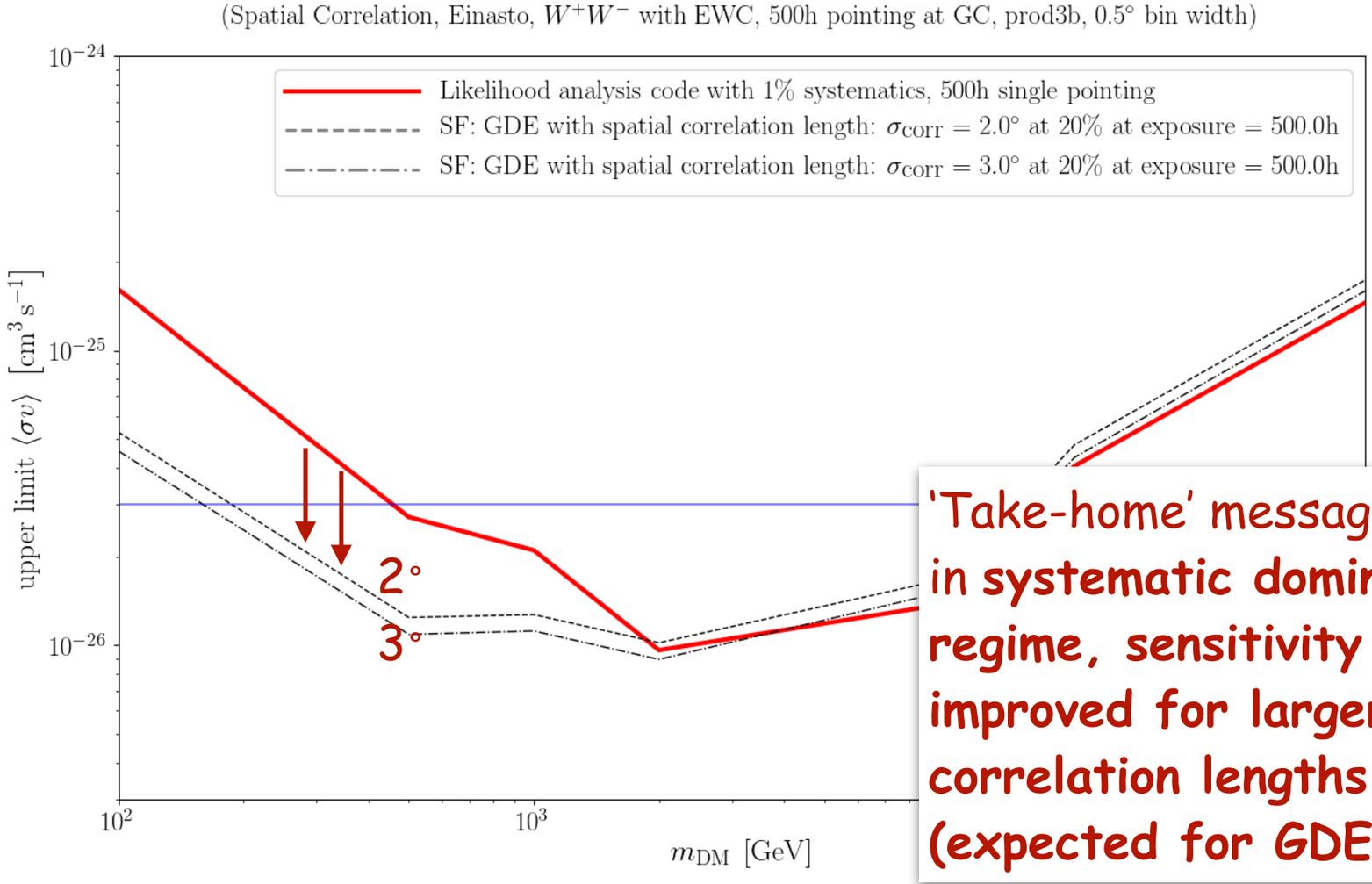

Assumes that we know CR backgrounds perfectly and have **20% syst on GDE, correlated at 2 and 3 deg length.**

'Take-home' message: - in **systematic dominated regime, sensitivity improved for larger correlation lengths (expected for GDE)**

CTA Consortium paper on DM sensitivity at the Galactic Centre

- summary

We use updated models of astrophysical emission at the GC (Fermi LAT + HESS) to study the realistic sensitivity of CTA to extended dark matter signals.

The goal is to define:

- most promising analysis strategy,
- level and types of systematic uncertainties,

needed to reach thermal cross-section sensitivity.

TeV DM reachable with CTA, for a set of realistic assumptions.

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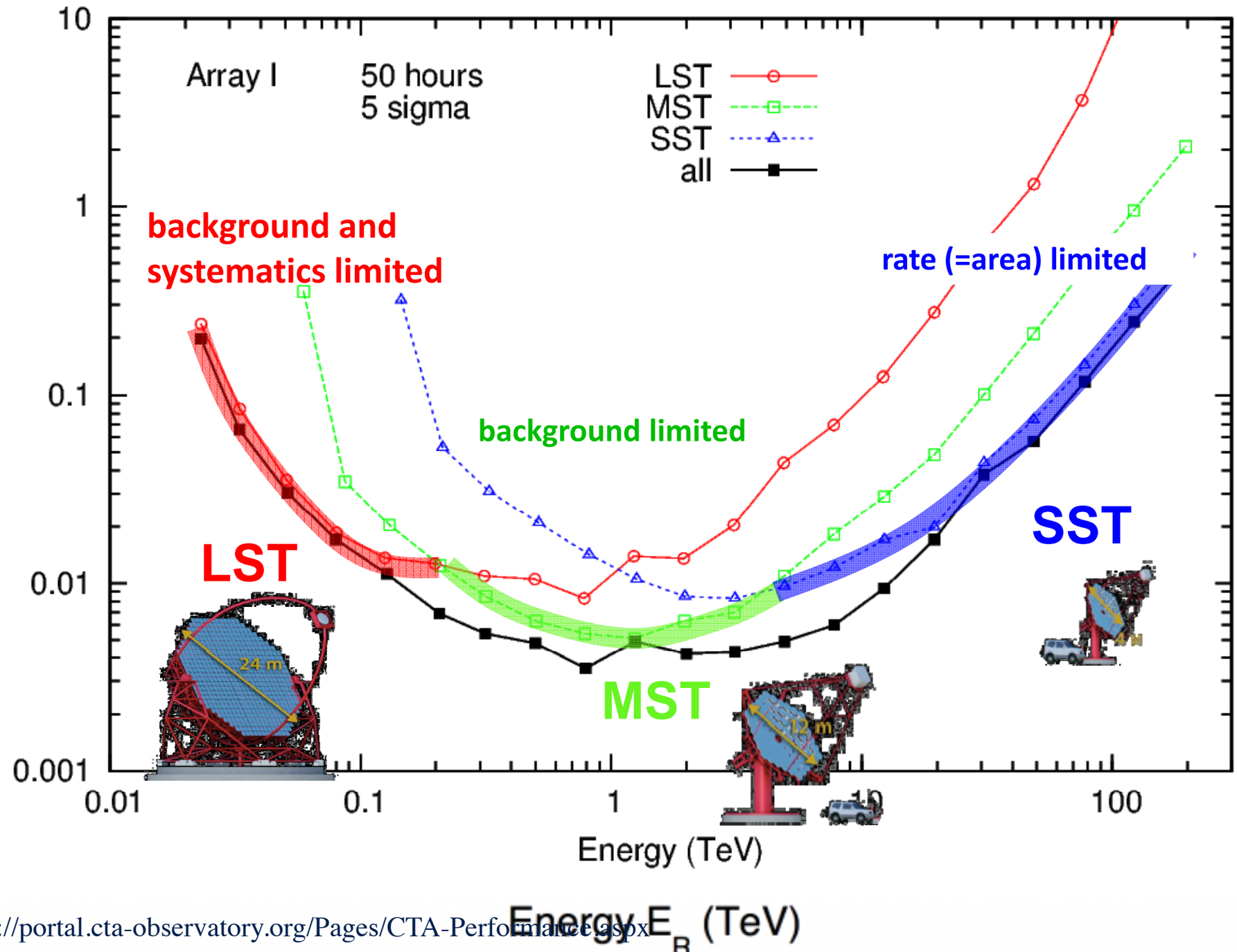
Stay Tuned!

Extra Slides

CTA

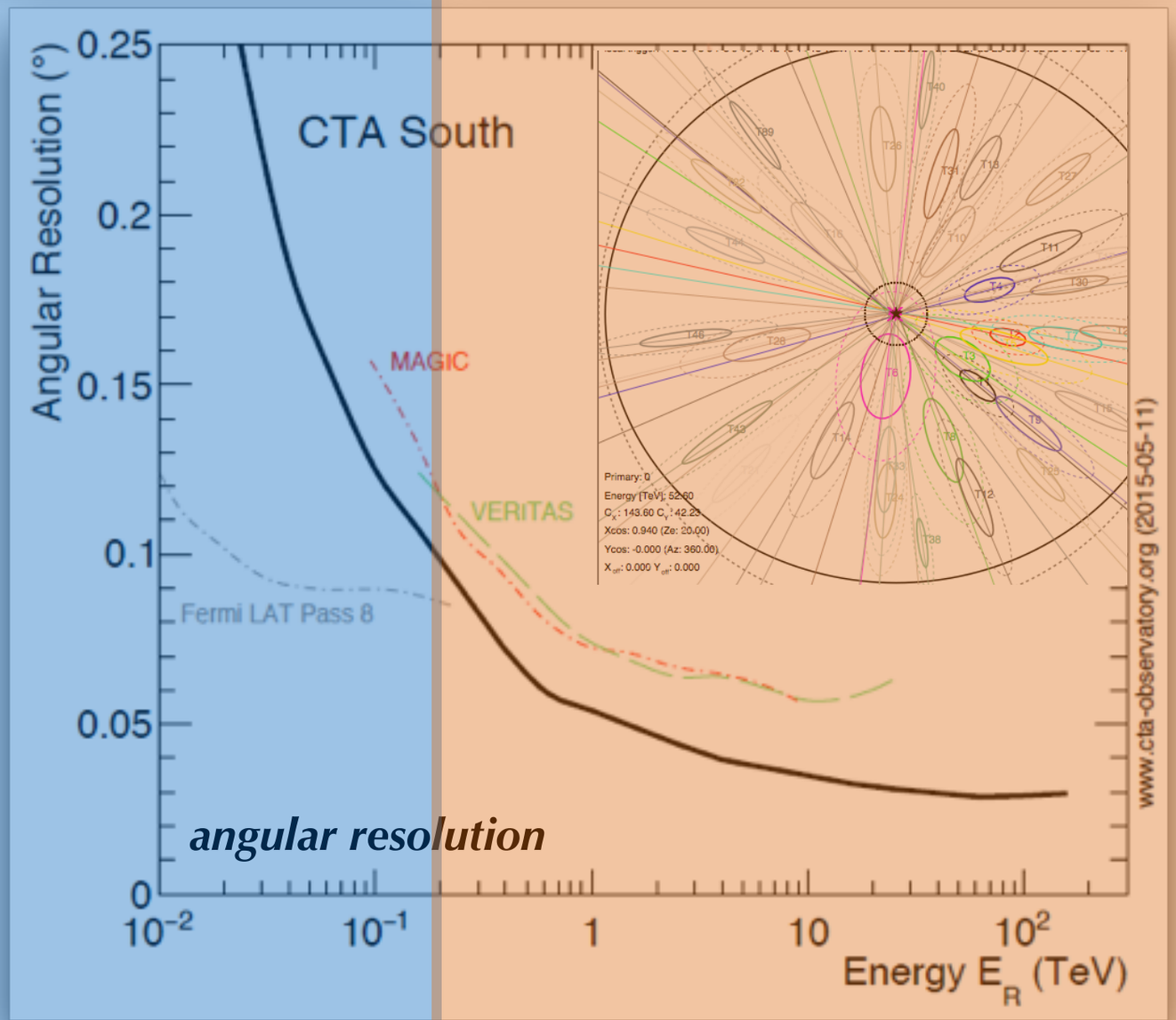
Performance



Instrument response functions at: https://portal.cta-observatory.org/Pages/CTA-Performance.aspx

CTA

Performance



angular resolution

CTA Consortium paper on DM sensitivity at the Galactic Centre

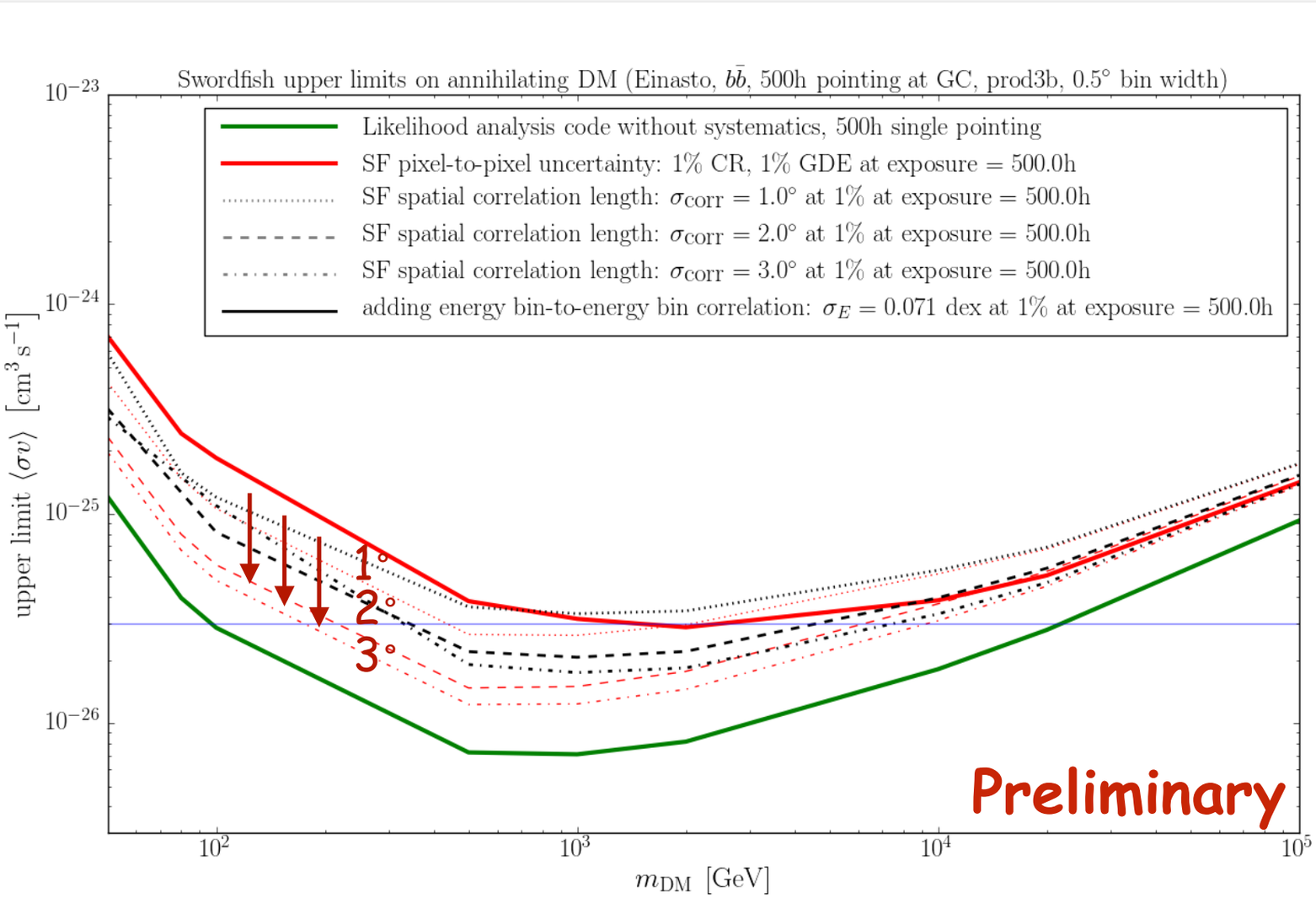
- status report

Some results:

→ with Morphological analysis, CR+GDE +1 % systematics

→ **Exploring correlations with the Swordfish tool** (Edwards&Weniger, JCAP (2018))

bb



Syst of 1% on CR background, but **correlated with 1, 2, 3 deg correlation length**

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Some results:

→ with Morphological analysis, CR+GDE +1 % systematics

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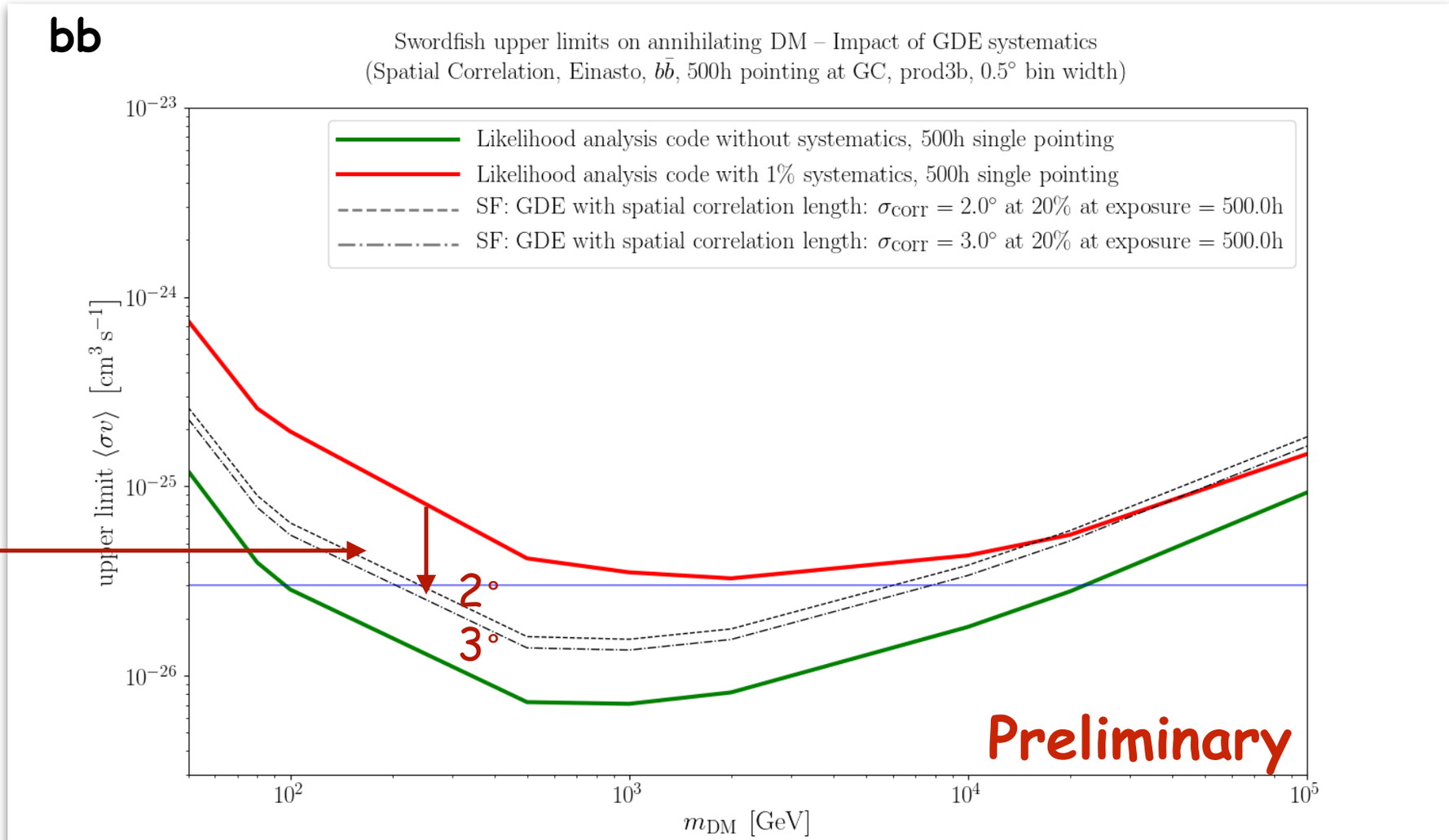
bb



Assumes that we know CR backgrounds perfectly and have **20% syst on GDE, correlated at 2 and 3 deg length.**